JANUARY 1951

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

One man – serving all three – saves your time

For more than twenty years Carbide and Carbon Chemicals has maintained a staff of technically trained representatives to serve its customers throughout the country. Now, more than ever, this policy means time and effort saved for you.

Every CARBIDE representative is a graduate chemist or chemical engineer. This basic technical knowledge, plus research experience in our laboratories, special training in our home office, and practical knowledge gained in the field, gives our representative the background needed to be of assistance to all three, the men in your plant, your laboratory, and your purchasing department.

When you have problems involving the use, development, or purchase of chemicals, call our nearest office and discuss them with a CARBIDE representative. And if you would like a copy of the 1951 edition of our booklet, "The Physical Properties of Synthetic Organic Chemicals," please call or write our nearest office.

CARBIDE AND CARBON CHEMICALS DIVISION

Union Carbide and Carbon Corporation

30 East 42nd Street New York 17, N. Y.

Offices in Principal Cities

In Canada:
Carbide and Carbon Chemicals, Limited, Toronto

Volume 47 Number 1

Chemical Engineering Progress

JANUARY 1951

OPINION AND COMMENT Page

CHEMICAL ENGINEERING PROGRESS
T. H. Chilton 1

ENGINEERING SECTION

RESISTANCE TO FILTRATION
E. H. Hoffing and F. J. Lockhart 3

GENERALIZED CORRELATION OF PROCESS VARIABLES MULTICOMPONENT SOLVENT EXTRACTION
C. Berg, M. Manders, and R. Switzer 11

HEAT AND MASS TRANSFER FLUID SOLID SYSTEMS
B. W. Gamson 19

SPRAY DRYING OF SANTOMERSE
J. C. Chu, L. E. Stout, and R. M. Busche 29

ELUTRIATION OF FINES FROM FLUIDIZED SYSTEMS
M. Leva 39

A GENERAL GRAPHICAL ANALYSIS OF CONTINUOUS REACTIONS IN SERIES OF AGITATED VESSELS
R. W. Jones 46

LETTER TO THE EDITOR

NOTATION FOR LARGE AND SMALL NUMBERS
J. W. Clegg 38

NEWS

PROBLEMS IN CHEMICAL ENGINEERING RESEARCH
E. R. Gilliland 11

WHITE SULPHUR SPRINGS MEETING 13

COLUMBUS ANNUAL MEETING 15

DATA SERVICE INSERT ..... *Following page* 18

INDUSTRIAL NEWS 22

CRITICAL SHORTAGE OF ENGINEERS
(Report to E. J. C. by S. C. Hollister) 26

MANPOWER PLANS SUBMITTED TO N.S.R.B. 28

MARGINAL NOTES 30

CANDIDATES FOR MEMBERSHIP IN A.I.Ch.E. 32

LOCAL SECTION NEWS 36

LOCAL SECTION CALENDAR 38

FUTURE MEETINGS 40

NEWS ABOUT PEOPLE 43

CLASSIFIED SECTION 46

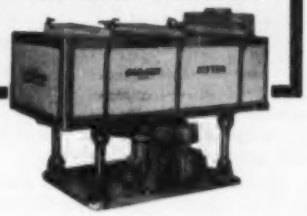
NECROLOGY 48

Editor: F. J. Van Antwerpen • **Publication Board:** T. H. Chilton, Chairman; W. I. Burt, Vice-Chairman; C. R. De Long, S. L. Tyler, W. L. McCabe • **Advertising Manager,** Lansing T. Dupree.

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Phjladelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, $6.00; Canada, $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1951 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulation. *Chemical Engineering Progress* is indexed regularly by Engineering Index, Incorporated.

GET BIG PRODUCTION CLEAN SEPARATIONS WITH

BAR-NUN ROTARY SIFTER



WHETHER you need large or small volume sifting production, check up on the BAR-NUN Rotary Sifter now! This precision, GUMP-Built rotary motion Sifter will give you continuous operation 24 hours, day and night. You can use it for sifting, grading or scalping. It will produce thorough single or multiple separations by particle size, of dry, flaked, granular and powdered materials. Made in 9 sizes, with 4 to 60 square feet of cloth surface. Send for complete information on this and other GUMP-Built Equipment listed in the coupon below.

TEAR OUT.. PASTE ON LETTER-HEAD AND MAIL TODAY!

B. F. Gump Co., 1311 S. Cicero Ave., Chicago 50

Gentlemen: Please send me descriptive literature and complete information on the GUMP-Built Equipment indicated below.

☐ BAR-NUN ROTARY SIFTERS for grading, scalping or sifting dry materials.

☐ DRAVER FEEDERS for accurate, dependable volume percentage feeding.

☐ DRAVER MASTER Continuous Mixing Systems for accurate, efficient, uniform mixing.

☐ VIBROX PACKERS for packing down dry materials in bags, drums, barrels.

☐ AUTOMATIC NET WEIGHERS for accurately weighing from 3 oz. to 75 lbs. for packaging or processing.

B.F.Gump Co.

Engineers and Manufacturers Since 1872

1311 SOUTH CICERO AVENUE
CHICAGO 50, ILLINOIS

caustic salt

Rinse water costs money—especially in the evaporator of an electrolytic caustic plant. The Sharples Super-D-Hydrator, with its completely automatic flexible operation, uses less rinse water to obtain low caustic concentration salt, thus costly steam is saved and the capacity of the evaporator is increased appreciably.

Two examples:

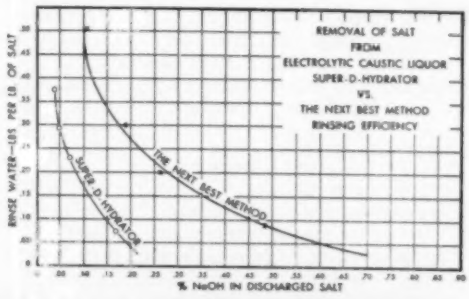
(1) On a feed slurry of 12-15% caustic soda, with 35-45% free sodium chloride, the Sharples Super-D-Hydrator produces sodium chloride with 0.15% (max.) caustic soda, and 2% (max.) moisture. Actual records show the use of but 25 gallons of rinse water per ton of dry sodium chloride produced.

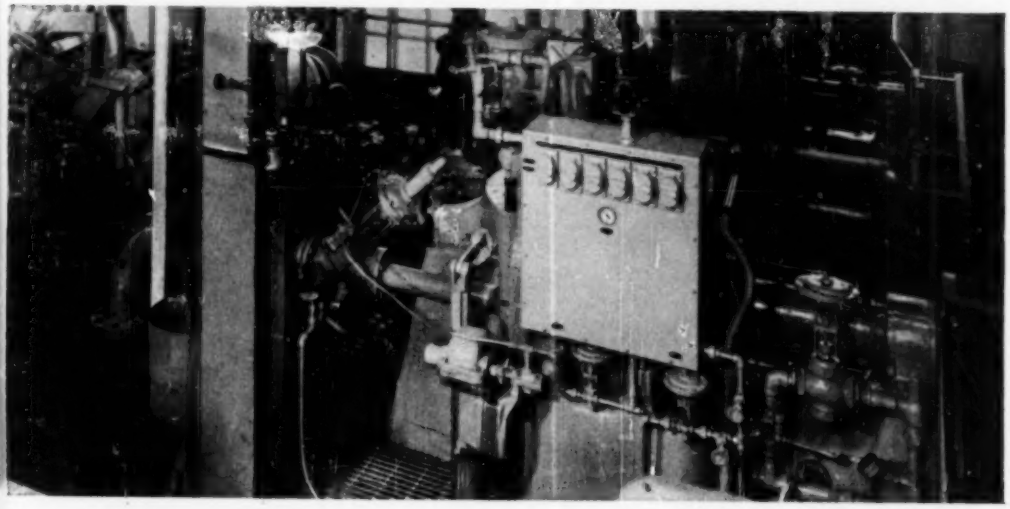
(2) On a 40% caustic soda slurry with 15-25% free sodium chloride, the Super-D-Hydrator produces salt with less than 0.40% caustic soda (max.) and less than 3% moisture—using but 45 gallons of rinse water per ton of sodium chloride produced.

These examples are typical of the high efficiency and economical operation of the Sharples Super-D-Hydrator.

Capacity ranges from 3000 lb./hr. of salt from 40% caustic mother liquor for the C-20 Super-D-Hydrator, up to 10,000 lb./hr. from 15% caustic mother liquor for the C-27 Super-D-Hydrator.

For caustic salt and dozens of other crystal dehydration applications, the Super-D-Hydrator is the proved best answer to production and economy. Your inquiry will be given our prompt attention.


REMOVAL OF SALT FROM ELECTROLYTIC CAUSTIC LIQUOR
SUPER-D-HYDRATOR VS. THE NEXT BEST METHOD
RINSING EFFICIENCY
RINSE WATER—LBS. PER LB. OF SALT
SUPER D-HYDRATOR
THE NEXT BEST METHOD
% NaOH IN DISCHARGED SALT



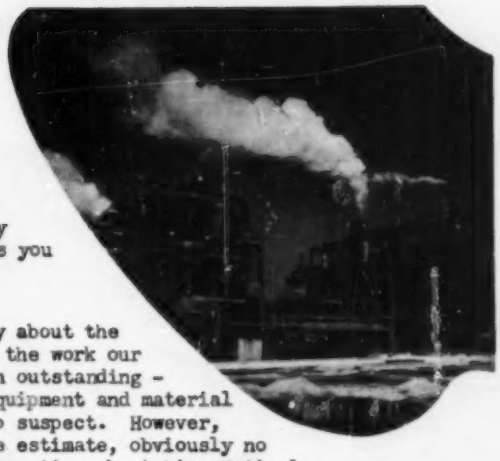
Super-D-Hydrator installation at Pennsylvania Salt Manufacturing Co., Wyandotte, Mich.

BOSTON NEW YORK PITTSBURGH
CLEVELAND DETROIT CHICAGO
NEW ORLEANS SEATTLE LOS ANGELES
SAN FRANCISCO HOUSTON

SHARPLES

THE SHARPLES CORPORATION

2300 Westmoreland Street, Philadelphia 40, Pa.



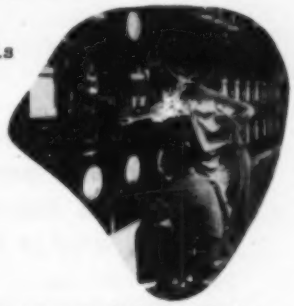
Dear Bill:

Thanks for your frank criticism. We try to say in our advertising a lot of the things you suggest. But some just can't be detailed.

For instance, we can't talk specifically about the cost of projects. I certainly do agree that the work our purchasing people have recently done has been outstanding - they really scurried around and are buying equipment and material at prices far under what we had any reason to suspect. However, although we often finish a job well under the estimate, obviously no client wants us to divulge specific cost information about his particular plant.

In our ads we sometimes speak of speed of completion and many of our projects are finished ahead of schedule with financial advantage to our clients in putting products on the market sooner. But, as you know, many factors affect a schedule and just plain speed doesn't always result in economy. There's no sense in sending a man out in the field to pour foundation if the stuff going on those foundations won't arrive for a couple of months. What we try to talk about is Badger's careful planning and coordination that produce savings in time and money.

Again, many times we develop new ideas in cooperation with a client's engineering staff, or adapt old ideas to new problems. The results are often immensely valuable to the client; yet to protect the client's interest we can't spell out our part in his success. Badger's fine reputation of ethical dealing is invaluable insurance to a client that his financial interests and industrial secrets will be protected, and is one of our most precious assets.



You ask why we don't emphasize more of our outstanding success stories, like those crude units which operated continuously for 796 days and processed 15,000,000 barrels without interruption. Well, we'd rather talk about our consistently good record than get into a bragging contest with our competitors.

Fundamentally we want to show how our broad experience in many varied fields is combined in one skilled, effective, integrated organization - and to emphasize Badger's basic know-how in the process industries.

Thanks for your letter though, Bill, and thanks for your other ideas which we will use during 1951.

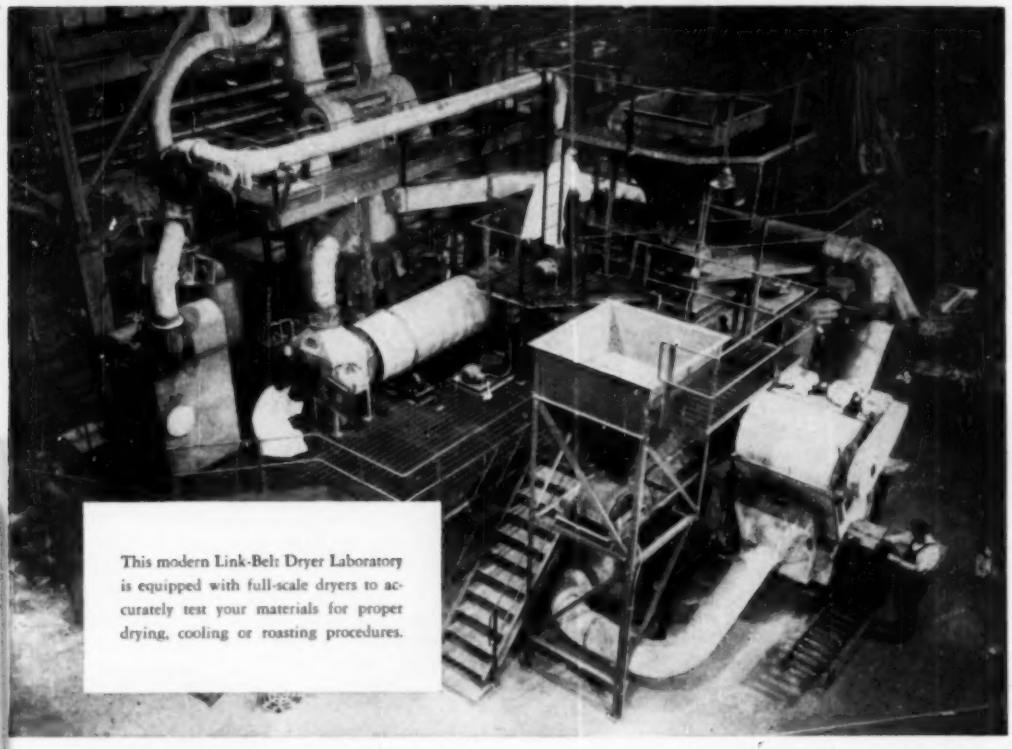
E.B. Badger & Sons Co. est. 1841 a subsidiary of Stone & Webster, Inc.

Boston New York

Process Engineers & Constructors for the Petroleum, Chemical & Petro-Chemical Industries

An invitation to manufacturers with

Drying, Cooling or Roasting Problems



This modern Link-Belt Dryer Laboratory is equipped with full-scale dryers to accurately test your materials for proper drying, cooling or roasting procedures.

LINK-BELT will test-run your material and work out procedures in this laboratory that can be duplicated in your plant...

Here's a practical suggestion: Send us a sample of your materials. We'll test them for the one best drying, cooling or roasting procedure. Based on more than 1,000 such tests, in the Link-Belt Dryer Laboratory, nearly 500 Link-Belt Dryers are now operating profitably throughout the world!

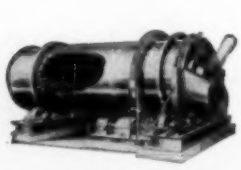
We can test a pound or a ton. But if your materials can't be shipped, we'll supply a unit (on a loan basis) for experiments in your own plant. Your nearest Link-Belt office or plant will gladly supply all details.

LINK-BELT COMPANY: Chicago 9, Indianapolis 6, Philadelphia 40, Atlanta, Houston 1, Minneapolis 5, San Francisco 24, Los Angeles 33, Seattle 4, Toronto 8, Johannesburg. Offices in principal cities.

12.203

LINK-BELT

DRYERS • COOLERS • ROASTERS



GLYCERINE

IMPORTANT FOR DRUGS...

...IMPERATIVE FOR NATIONAL DEFENSE!

In every hospital and as close to home as your corner drugstore, U.S.P. Glycerine and its derivatives work round the clock in the service of medicine and pharmacy. A vehicle, lubricant, emollient, solvent and vasodilator—Glycerine offers such an unusual combination of properties that no single substitute may be used to replace it in original formulas of the U.S. Pharmacopoeia!

—That explains why Glycerine has been included among the first 6 chemicals to be placed under inventory control*...

—and why it is sometimes not immediately available when lifesaving pharmaceuticals and biologicals, salves and ointments for the military must supersede civilian or non-critical requirements.

*By Government authorities responsible for inventory control under the National Defense Act.

GLYCERINE PRODUCERS' ASSOCIATION
295 Madison Ave., New York 17, N. Y.

Longer service life at lower final cost

with dependable CRANE VALVES

No. 1610 Diaphragm Valve. Ask for literature on full line through your Crane Branch or Crane Wholesaler.

CASE HISTORY FROM CRANE FILES

PROBLEM: To find a more efficient and economical replacement for plug cocks having an average life of only 2 to 8 weeks in pipe lines handling liquid clay to filter presses.

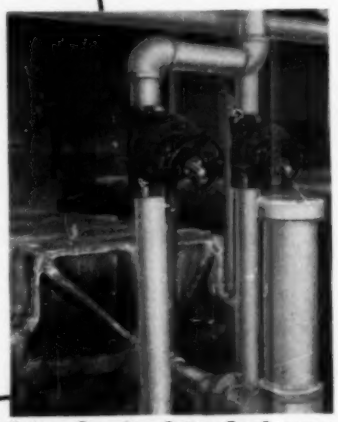
WORKING CONDITIONS: Working pressure 140 psi, with liquid clay flow creating highly erosive effect; also corrosive. Strong tendency to clogging. Operating cycles 5 to 6 per day; relatively quick opening and closing required.

SOLUTION: Crane No. 1610 Diaphragm Valves, iron body, packless design, with separate disc and diaphragm.

RESULT: After 11 months' uninterrupted service, Crane valves showed no significant wear or damage resulting from normal operating conditions. User assured of greatly reduced maintenance and replacement costs over plug cocks. No. 1610 Diaphragm valves approved for standardization on all filter press piping.

Another example of the greater value in Crane Quality, and the lower final cost of Crane Valves for every service. That's why . . .

More CRANE VALVES are used than any other make!



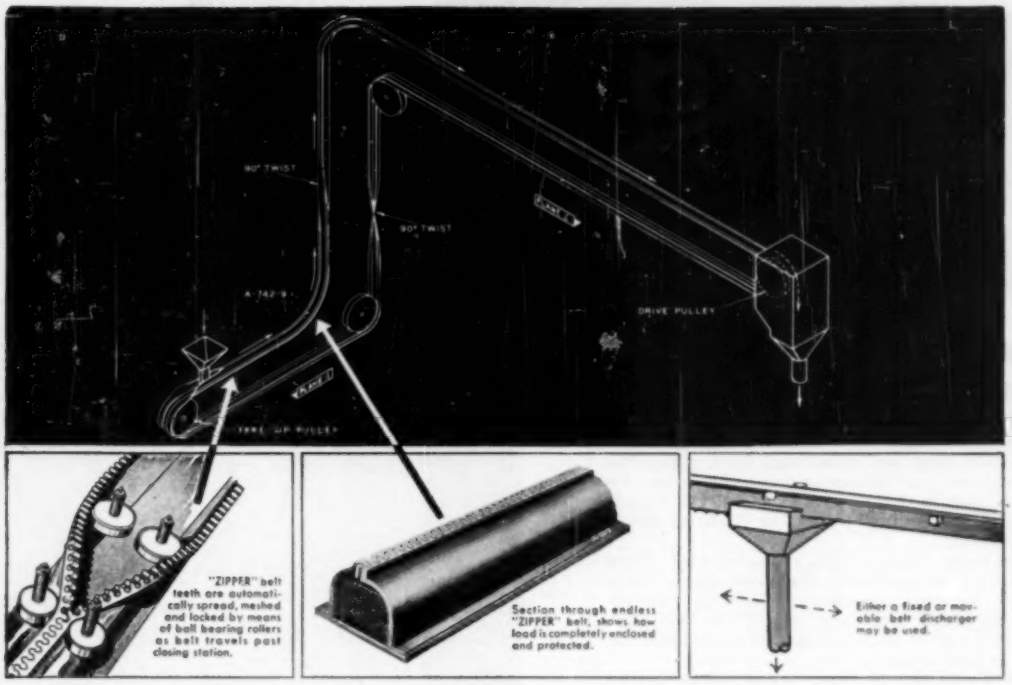
The installation—Onondaga Pottery Co., Syracuse

CRANE

CRANE CO., *General Offices:* 836 S. Michigan Ave., Chicago 5, Ill.

Branches and Wholesalers Serving All Industrial Areas

VALVES • FITTINGS • PIPE • PLUMBING • HEATING


90° TWIST
90° TWIST
DRIVE PULLEY
"ZIPPER" belt teeth are automatically spread, meshed and locked by means of ball bearing rollers as belt travels past closing station.
Section through endless "ZIPPER" belt, shows how load is completely enclosed and protected.
Either a fixed or movable belt discharger may be used.

"ZIPPER"—Has One "RUBBER MUSCLE"

—As Flexible as a Hose!

"ZIPPER"—the new conveyor-elevator developed by S-A engineers, does the work of several conventional conveyor-elevators. But, with its one continuous "rubber muscle", "Zipper" does the same work, in less space, and with the elimination of extra drives, transfer spouts, casing, breakage and dust.

"Zipper" conveys horizontally, vertically or on inclines—in any direction and in any plane. Sidewalls are closed around the load to eliminate spillage and escape of dust as well as contamination from outside. "Zipper" moves around obstructions—carries its load gently without breakage or segregation.

Belt opens for complete discharge and cleaning when necessary. Speeds may be regulated up to 200 FPM. Pulverized, granular, lumps or flaky materials are particularly suited to "Zipper" application. This system is not only "flexible" in operation but also in its adaptability to many applications—probably including some problem of yours.

Ask for recommendations of S-A engineers on how new "Zipper" can serve you. There's no obligation so write today.

FOR EXAMPLE AT
MANSFIELD SANITARY
POTTERY, INC.
PERRYSVILLE, OHIO

1" dry ball clay and other fine materials are drawn from storage silos and delivered to cylindrical underground dump hopper equipped with an S-A two-stage circular bin discharger. Materials are fed to "ZIPPER" belt conveyor which moves 32 feet upward, and makes a 90-degree turn to processing building. Over 95 feet of horizontal run over 5 mixing tubs, movable belt discharger can be spotted over any mixer. This S-A "ZIPPER" system fitted into existing layout without structural alterations.

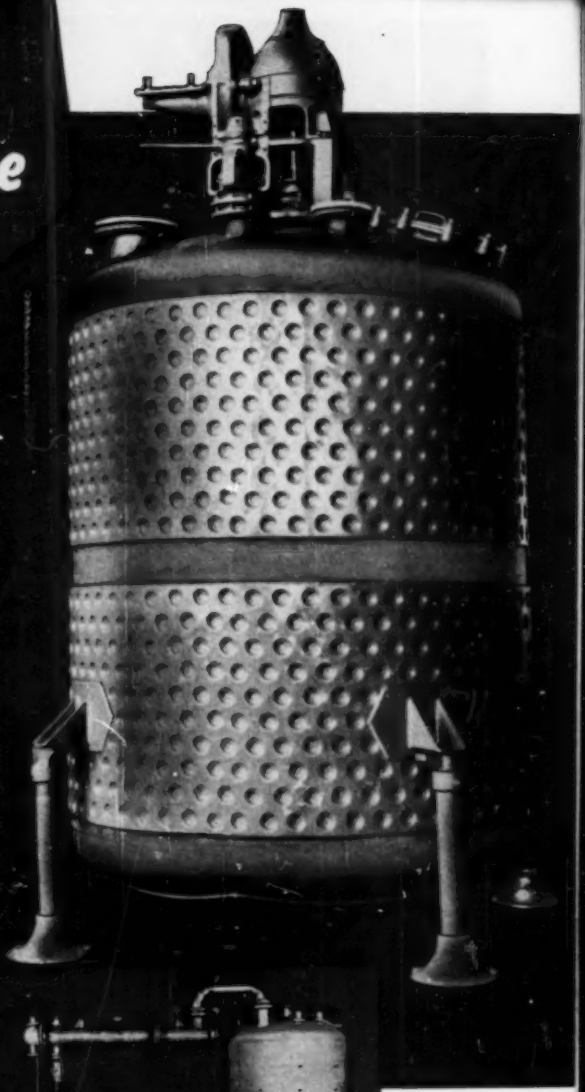
STEPHEN S-A DAMSON MFG. CO.

57 Ridgeway Avenue, Aurora, Illinois — Los Angeles, Calif. • Belleville, Ontario

DESIGNERS AND MANUFACTURERS OF ALL TYPES OF BULK MATERIALS HANDLING EQUIPMENT

MORE FOR YOUR

PLUS Better Performance



Why it pays to check with Pfaudler on your custom-built process equipment requirements

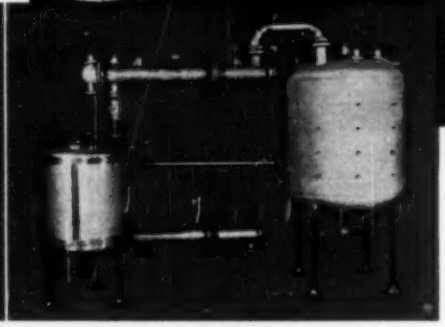
Just about 46% of the processing requirements for Pfaudler equipment are met by standardized stainless steel and glass-lined steel units. Pre-engineered and built on a production basis, this equipment makes possible substantial savings in both price and delivery—all of which are passed on to you.

Pfaudler does not stop there, however. When standard designs won't meet the capacity, pressure, or other requirements involved, you obviously need something special. On this work Pfaudler offers similar design advantages that can mean real savings to you.

For example, the large stainless steel reactor shown above would have cost far more had the jacket been built in the conventional way. Instead, Pfaudler engineered a "dimpled" jacket which permits higher pressures *without* a commensurate increase in steel thickness of relatively high priced alloy. Thus, the purchaser got more for his money without any sacrifice in performance.

You see, Pfaudler engineering groups are specialized in the fields of processing, corrosioneering, design and fabrication. All work together, give you more for your money *plus* better performance. Send us your bids!

Regardless of how specialized your processing requirements are, Pfaudler is well qualified to offer sound construction with maximum economies.



The "dimpled" jacket construction on this special stainless steel reactor saved over $600.00 in material costs alone.

Pfaudler

THE PFAUDLER CO., Rochester 3, N. Y. Branch offices: 330 W. 42nd St., N. Y. 18, N. Y.; 111 W. Washington St., Chicago 2, Ill.; 818 Olive St., St. Louis 1, Mo.; 2070 West Grand Blvd., Detroit 2, Mich.; 1719 1st Nat'l Bank Bldg., Cincinnati 2, Ohio; 1041 Commercial Trust Bldg., Philadelphia 2, Pa.; 751 Little Bldg., Boston 16, Mass.; 334 Chattanooga Bank Bldg., Chattanooga, Tenn.; P. O. Box 4066, Dallas, Texas; Taylor St., Elyria, Ohio; 1346 Connecticut Ave., N. W., Washington 6, D. C.; 121 Bauman Ave., Pittsburgh 27, Pa.; P. O. Box 1031, Minneapolis, Minn.; The Pfaudler Sales Co., 1325 Howard St., San Francisco 3, Calif., 3757 Wilshire Blvd., Los Angeles 5, Calif.; Enamelled Metal Products Corp., Ltd., Artillery House, Artillery Row, London, S. W. 1, England.

THE PFAUDLER CO., ROCHESTER 3, NEW YORK

Engineers and Fabricators of Corrosion Resistant Process Equipment

GLASS-LINED STEEL
Hastelloy—Aluminum
Tantalum—Carbon Steel
Solid or Clad Stainless Steel
Nickel, Inconel, Monel

OPINION AND COMMENT

CHEMICAL ENGINEERING PROGRESS

IT is no coincidence that the title of this discussion is the same as that of the magazine in which it appears. For the chemical engineering progress on which I want to offer opinion and comment is that which has been made by this, the official organ of the Institute, and that which is related to our publication program.

With the completion of four full years of publication, C.E.P. has established a distinctive place for itself. It may not be generally recognized, however, how much progress it does represent over the former "Transactions." Let's look at the record.

Compared with "Transactions" on the basis of equivalent annual pages of technical matter, equivalent pages of "Bulletin," news, or nontechnical matter, cost to the individual member, and annual number of technical papers printed, C.E.P. has three solid accomplishments to its credit. They are:

1. The ratio of technical pages published by C.E.P. to the technical pages published in the "Transactions" is about 2.25. The ratio for non-technical pages is about 10.5, and the ratio for total pages is about 3.2.
2. The direct cost per member (not including the capital cost of setting up C.E.P. and covering its deficits during its first years of operation) is the $4.50 of membership dues (there is no deficit in the magazine operation for 1950), compared with a cost of "Transactions" of about $4.75. Allowing for inflation, the present cost to the member is approximately $2.70 in terms of prewar money.
3. The present capacity of C.E.P. is about 95 technical papers per year. The "Transactions" published an average of 37 papers per year over the period 1936-45. This is a ratio of about 2.5 in favor of C.E.P.

The Institute has never, of course, obligated itself to publish all papers presented at meetings. While accepting papers for the programs on the understanding that they become the literary property of the Institute, nevertheless it reserves the privilege of publication for those papers judged (by the editor, now, of C.E.P., aided by such reviewers as he may call upon) to be deserving of it. Of the 412 papers presented at the meetings held between September, 1946, and August, 1950, 249, or nearly two thirds have appeared in C. E. P. to date, a creditable proportion. In addition to this number, a few were from prior meetings; as against those, 63 were still under consideration at the end of 1950.

In addition to papers presented at meetings, the Institute publishes contributions submitted directly. In these four years, C. E. P. has published 143 such papers. A number of the manuscripts so offered are referred to the Program Committee, and if appropriate and the authors are agreeable to the suggestion, some are afforded the opportunity for presentation before publication. With four meetings per year, this becomes a feasible procedure.

With four meetings a year, however, the possible number of papers presented—143 in 1950—clearly exceeds the present capacity of C.E.P. to handle, with any allowance for worth-while direct contributions. A problem clearly remains as to possible means of handling the papers that are available to the Institute and should be published by the Institute. The problem is made more acute by a continuing successful series of technical symposia, which ought to be published as a group, yet which if it were to be done would exclude all other technical matter from one or more monthly issues of C.E.P.

After much deliberation, the Publication Committee reached the conclusion that a solution to the chronic and now acute problem could be found in separate publication of such groups of papers as were represented in these technical symposia. Accordingly, the recommendation was made to and accepted by the Council that the Editor be authorized to proceed with such a program, such separate publications to be issued at such a price as to cover the cost. Details, agreed upon by those interested at the meeting in Columbus, will be announced in appropriate news columns, but essentially they will follow this outline: the separate publications will be designated as successive numbers in a Symposium Series of CHEMICAL ENGINEERING PROGRESS, of the current volume and year; they will be available for purchase separately, at a price to be determined at the time of issuance; subscriptions would be accepted, however, from those who wish to make certain that they will receive all numbers, on a "when, if, and as issued" basis. The Editor will satisfy himself as to the suitability of the papers for publication, by securing reviews or otherwise, as in the case of articles published in C.E.P. He may include other available articles, if of equal quality and germane to the subject, though not actually presented at the symposium being reported. Copies will be made available to the indexing services and abstracting periodicals, so that the contents will become part of the permanent literature. CHEMICAL ENGINEERING PROGRESS will carry appropriate notices, tables of contents, and a yearly index of authors and subjects to bring the material to the attention of A.I.Ch.E. members and C.E.P. subscribers.

The program will get under way shortly, and the officers and Publication Committee will welcome the views of the membership on it when the first numbers in the "Symposium Series" have appeared.

In its stated object of "advancement of chemical engineering in theory and practice," the Institute can do other things beside publish articles. A proposal for an extension of its activities was submitted by the New York Section early in 1950, along the line of securing adequate critical reviews or monographs in the field of chemical engineering. After considering the merits of alternate proposals, such as the establishment of a new review-type magazine, and a plan for setting up a staff reporter who would prepare summary articles for publication in CHEMICAL ENGINEERING PROGRESS which would be expected to stimulate the writing of treatises on the subject covered, the New York Section favored the establishment of a monograph series, financed initially by the Institute.

The Publication Committee has given extended consideration to this proposal also. The reality of the problem was recognized, and the merits of the recommendation. It was concluded, however, that, as presented, the financial commitment was greater than the Institute was prepared to accept. As a start in the direction indicated, the suggestion was put forward that the Institute lecturer for the year be invited to furnish an extended manuscript suitable for publication on the subject of his lecture, with a payment to defray costs incurred in its preparation. This suggestion has been concurred in by the Council, and has been accepted by the 1950 lecturer. His manuscript will then appear before long as No. 1 in a companion "Monograph Series," which will also be available for purchase or subscription.

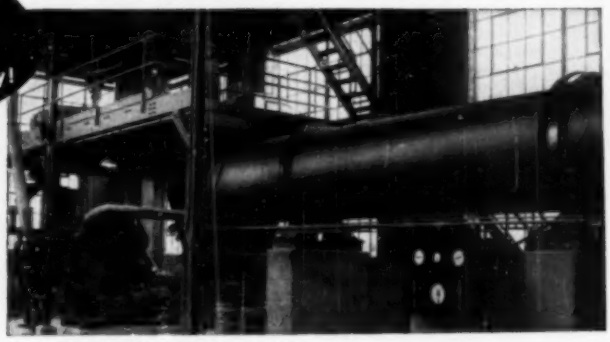
To conclude as I began, I venture the opinion and offer the comment that the establishment of CHEMICAL ENGINEERING PROGRESS with the service that it renders to the membership of the Institute, and the extensions of this service now under way, constitute real and substantial chemical engineering progress.

THOMAS H. CHILTON, *President, A.I.Ch.E.*

See Louisville for
CREATIVE
DRYING
ENGINEERING

New Louisville Chemicals Dryer costs less, does 50% more work . . . at 77% less operating expense

KNOW THE RESULTS Before You Buy!



FORMER DRYER

Installed cost	$40,000
Annual production (tons)	6,000
Drying cost per ton	3.72

(space required, 1500 sq. ft.)

LOUISVILLE DRYER

Installed cost	$20,000
Annual production (tons)	9,000
Drying cost per ton	0.83

(space required, 500 sq. ft.)

YEARLY SAVINGS of LOUISVILLE DRYER in OPERATING COSTS ALONE $14,850

Other General American Equipment: Turbo-Mixers, Evaporators, Thickeners, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels

A magician's creation? No! The Louisville Dryer described here was installed by a chemical processor after his production was completely analyzed by a Louisville engineer. By using advanced, complete knowledge of drying processes, this dryer was especially designed to fit into his production line after the dryer's performance was pre-determined in our own unique research laboratories and pilot plant.

Without obligation ask a Louisville engineer to survey your drying methods. He may come up with a better solution that costs you less for faster, more satisfactory production.

PROCESS EQUIPMENT DIVISION GENERAL AMERICAN TRADE MARK

Louisville Drying Machinery Unit

Over 50 years of creative drying engineering

GENERAL AMERICAN TRANSPORTATION CORPORATION

Dryer Sales Office: Hoffman Bldg., 139 So. Fourth Street Louisville 2, Kentucky

General Offices: 135 South La Salle Street, Chicago 90, Illinois

Offices in all principal cities

RESISTANCE TO FILTRATION

EDGAR H. HOFFING† and FRANK J. LOCKHART

University of Southern California, Los Angeles, California

IN recent years the understanding of the basic mechanism of filtration and fluid flow through porous beds has been advanced and unified tremendously. Theoretical equations for fluid flow through porous beds have been derived and proved reasonably well. The similarity of filtration and fluid flow through porous beds has been recognized for some time, and it has been suggested that the theoretical equations for permeability should be directly applicable to filtration. Direct experimental data have not been reported to substantiate this viewpoint. This present paper presents such data, and also gives some supplementary data concerning the specific resistances to filtration and permeability.

Previous Work

Although some workers (*2*) have advocated the Reynolds number—friction factor concept in predicting filtration and permeability characteristics, most investigators have used the concept of specific resistance. A review and bibliography of these two processes to 1938 are given by Carman (*4*).

Filtration. Filtration is the process in which a liquid is separated from solids suspended in the liquid by passing the liquid through a porous medium or septum, and collecting the separated solids as a cake formed on the septum. The usual filtration equation is based on Poiseuille's law, and assumes that the filter cake contains many small capillaries, through which the flow of the fluid is streamline. It may be written in differential form as:

$$\frac{dV}{Ad\theta} = \frac{P}{\mu} \times \frac{1}{(\text{resistance})} \qquad (1)$$

where V is the volume flowing in time θ past cross section of area A, etc. (*See* Notation.)

It has been found convenient to separate the resistance term in Equation (1) into the initial or septum resistance and the specific cake resistance. Using the terminology of Carman (*4*), Equation (1) becomes:

$$\frac{dV}{Ad\theta} = \frac{P}{\mu} \times \frac{1}{\frac{V}{A} v r_{fv} + R} \qquad (2)$$

Reference books (*11, 14*) give slight modifications of Equation (*2*). The term r_{fv} is the average specific resistance to filtration of a unit cube of the cake, and using c.g.s. units, is expressed in net dimensions of sq.sec./cc.*

Under constant pressure conditions, Equation (*2*) integrates to

$$\theta = \frac{\mu v r_{fv} V^2}{2PA^2} + \frac{\mu R V}{PA} \qquad (3)$$

or,

$$\frac{\theta}{V} = \frac{\mu v r_{fv} V}{2PA^2} + \frac{\mu R}{PA} \qquad (4)$$

Equation (4) gives a straight line when θ/V is plotted against V. The specific cake resistance to filtration can be calculated from the slope b of this line,

$$r_{fv} = \frac{2bPA^2}{\mu v} \qquad (5)$$

In many cases it may be more convenient to express the cake resistance as the average specific resistance per unit weight of the solids, r_{fw}, of net dimensions sq.sec./g. in c.g.s. units (actually, (sq.sec. × g. force)/(g. mass)²). In this case,

$$r_{fw} = \frac{v}{c} r_{fv} = \frac{2bPA^2}{\mu c} \qquad (6)$$

Permeability. D'Arcy stated the basic concept for laminar flow through a porous bed. In later years considerable data have shown the rate of flow through porous beds to be inversely proportional to the viscosity of the fluid, so that D'Arcy's equation is usually modified as follows:

$$\frac{dv}{Ad\theta} = \frac{P}{\mu L} K \qquad (7)$$

where K is called the permeability coefficient. The specific resistance to permeability on a volume basis (sq.sec./cc.) is defined as the reciprocal of the permeability coefficient. Equation (*7*) may be written as

$$\frac{dV}{Ad\theta} = \frac{P}{\mu L} \frac{1}{r_{pv}} \qquad (8)$$

It is seen that the modification of D'Arcy's law (Equation (*8*)) is the equivalent of Poiseuille's law for laminar flow through capillaries (Eq. (*1*)).

The specific resistance to permeability on a weight basis (sq.sec./g.) may be obtained from the relation:

$$r_{pw} = \frac{r_{pv}}{(1-\epsilon)\rho'} \qquad (9)$$

where ϵ is the porosity of the granular bed, i.e., the volume of pore space per volume of granular bed, and ρ' is the true density of the solid in grams per cubic centimeter.

The many theoretical and empirical studies over the years which have tried to relate the permeability with certain physical properties of granular beds have been summarized recently (*2, 4, 13*). The most successful relation is that presented by Kozeny (*9*) and Fair and Hatch (*7*) which considers a granular bed as equivalent to a single passage whose size is given by the hydraulic diameter corresponding to the volume and surface area of the voids in the bed. Kozeny's equation may be written in the form:

$$r_{pv} = \frac{5S_o^2(1-\epsilon)^2}{g_c\epsilon^3} \qquad (10)$$

where S_o is the specific surface of the solid particles in sq.cm./cc. Many investigators have verified this relation over a wide range of conditions. Carman (*3*) was so impressed with its accuracy that he proposed it as a method of obtaining surface area from permeability data.

Correlation between Filtration and Permeability. Carman (*4*) pointed out that it should be possible to calculate the specific filtration resistance from Equation (10) but stated that there was no case in which values calculated from Equation (10) had been compared with those derived from a constant pressure filtration curve.

Ruth (*12*) attempted to correlate filtration characteristics with permeability

NOTE: The Appendix to this paper containing the original data and calculated results (Tables 5-8) and a complete sample calculation is on file (Document 2834) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Microfilm is obtainable at 50 cents and photoprint at 80 cents.

† Present address: Great Lakes Carbon Corp., Los Angeles, Calif.

* When the distinction between mass grams and force grams is ignored. The addition of the g_c term would change the units of r_{fv} to (cm.)⁻².

Fig. 1. Diatomaceous earth (×370). One small division equals 2.9μ.

and particle size. He found that the specific resistance calculated from permeability data was about 15% less than that from constant pressure filtration tests, but was inclined to attribute this difference to aging of the calcium carbonate; there was apparently a considerable time lag between the filtration tests and the permeability tests. He further stated that in four years, the specific filtration resistance of this material had decreased to about 75% of the original. For these reasons, quantitative conclusions cannot be drawn from his data.

Walas (*13*) correlated filtration resistance with particle size and porosity for slurries of various compressible materials. His empirical equation gives the specific filtration resistance as being inversely proportional to the 1.02 power of the particle diameter, whereas the Kozeny equation states that it should be inversely proportional to the square of the particle diameter. Since Walas determined the particle diameters by a sedimentation method, and assumed that the "shape factor" was the same for the nine different materials, his equation is subject to question.

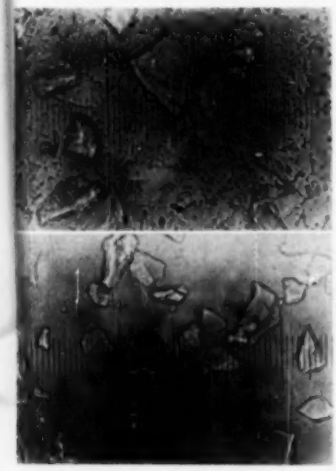


Fig 2 (top). Unseparated quartz (×370). One small division equals 2.9μ.

Fig. 3 (bottom). 10-20 micron quartz (×370). One small division equals 2.9μ.

Experimental Work

Materials. In order to test the correlation between filtration and permeability adequately, systems were required which varied widely in porosity, surface area, and specific resistance. It was decided to blend various amounts of a chemically inert material, quartz, with an equally inert and chemically similar material, diatomaceous silica, so that changes in physical properties caused by aging and chemical activity could be eliminated. Although these materials are similar in chemical and electrokinetic properties, they have a marked difference in physical properties. Quartz is made up of rhombohedral crystalline particles with low porosities—about 0.40. The diatomaceous silica used in these experiments is the calcined skeletal remains of marine plant life called diatoms. The diatoms are primarily amorphous silica having shapes varying from long pencil-like spicules to platelike discs. Among their more important properties are the high porosity and the large surface area. They form beds which are extremely permeable to the passage of fluids and yet are able to trap and remove colloidal particles from a fluid. Table 1 gives a comparison between some of the chemical and physical properties of quartz and diatomaceous earth. The diatomaceous earth used in these tests was obtained from the Dicalite division and is known as "Special Speedflow."

Figure 1 shows a sample of the diatomaceous earth used in these tests when magnified 1100 times. The disc shown in the photomicrograph has a diameter over 120μ. Many of the spicules are more than 400μ in length, though their thicknesses may be only 2 or 3μ. Thus, it is difficult to assign an average value of diameter to such a system. This photomicrograph makes it easier to understand how a cake made of these discs and spicules exhibits such a high porosity, even up to 90% void volume.

To obtain an even wider range of resistances, the quartz was separated by successive settlings into the following ranges of particle size: 10-20, 5-10, 3-5, 2-3, and 1-2μ. The particles were assumed to be spherical and to obey Stokes' law.

$$u = \frac{gD(\rho' - \rho)}{18\mu} \qquad (11)$$

where u is the linear velocity in cm./sec., and D is the average diameter of a particle in centimeters. The quartz was dispersed in water and five or six successive settlings and decantations were made in order to obtain uniform particle sizes in each of the fractions.

Figures 2 through 7 are photomicrographs of the quartz. The original or "As Is" quartz, the 10-20, and the 5-10μ samples are magnified 1100 times. The 3-5, 2-3, and 1-2μ samples were taken with an electron microscope and are magnified 4300 times. These photomicrographs show that the majority of the particles fall within the micron range designated for them. Although the particles are not spherical, they are regular and an average diameter may be assigned to them.

Filtration Tests. All filtrations were made using a laboratory bomb filter press (*8*), the essential features of which are shown in Figure 8. Two pressure vessels used to hold the slurry are made of 10-gage, 18-8 stainless steel, and have a total capacity of 2000 cc.; they may be used in parallel or in series. A removable gasketed lid is bolted to the top of each pressure vessel. Compressed air passing through a regulator into the bottom of each vessel creates the pressure differential across the filter leaf and provides agitation by bubbling up through the slurry. A pressure release valve is in the lid and the pressure is measured by a mercury manometer. A side connection to the drainage arm enables a precoat to be applied to the filter cloth. The filter leaf is made of two parts, the upper part being attached to the drainage arm of the pressure vessels. The lower part of the filter leaf is corrugated to enable free flow of the filtrate. The filter leaf is in a horizontal position, which has the advantage of preventing the precoat from collapsing with any jarring.

The slurry for the filtration tests was prepared by dispersing 2 g. of the solids in 1000 cc. of water. It was poured into the pressure vessels with valve *A* closed (*see* Fig. 8), and the air regulator set so as to allow a continuous stream of air to bubble through the slurry for agitation. The lids to the pressure vessels were bolted into place, and the air regulator valves were opened until the manometers read the desired pressure (10 lb./sq.in. gage). The filter cloth was fit on the lower leaf and clamped in place.

A slurry of only diatomaceous earth in distilled water was prepared in sufficient amount to provide a precoat equal to 10 lb./100 sq.ft. of filter area. The precoat was applied by drawing this slurry through the leaf. Valve *B* was then closed. Valve *A* was opened, a stopclock was started with the appearance of the first drop of filtrate. Volume readings were taken after 30 sec., 1, 2, 3, 5, 7, 9, 11, 13, and 15 min.

Permeability Tests. Permeability tests were made with simple laboratory apparatus. A section of a 50-cc. burette having a volume of 15 cc. and a cross-sectional area of 1.77 sq.cm. is used as the measuring cylinder. It is made to fit into a one-hole rubber stopper with a filter cloth between it and the stopper. A coarse wire gauze acts as a support for the cloth. The stopper fits into a filter flask which is in turn connected to a vacuum system.

One-tenth of a gram of diatomaceous earth of a different color than that used in the experiments was dispersed in distilled water. This slurry was used to form a precoat which was applied by drawing 20.36 in. of mercury vacuum (10 lb./sq.in. pressure difference) through the side arm of the filter flask. Distilled water was added to the tube before the precoat had a chance to blow dry, and the reciprocal rate of passage of clear distilled water through the cake and cloth was measured.

From 1 to 4 g. of sample to be tested, depending upon the composition, were dispersed in distilled water. Variations in the weight of the sample were used to obtain a fairly uniform volume of cake. This slurry was added before the precoat blew dry. To minimize settling, a fine glass tube was set down into the measuring cylinder at a height about ½ in. above the cake and a fine stream of air was bubbled through the tube. When all solids had formed a cake, distilled water was added carefully before the cake blew dry, and the time for 1 cc. to pass through the cake was noted. Two such runs were made for each sample and

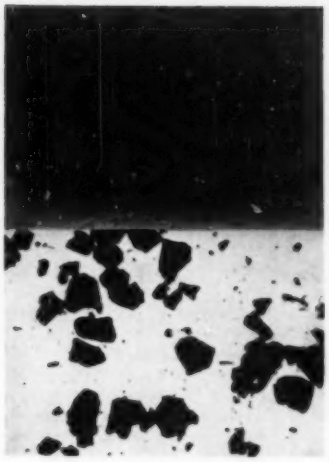


Fig. 4 (top). 5-10 micron quartz (×370).
One small division equals 2.9μ.

Fig. 5 (bottom). 3-5 micron quartz (×1400).
One centimeter equals 7.2μ.

TABLE 1.—SOME CHEMICAL AND PHYSICAL PROPERTIES OF QUARTZ AND KIESELGUHR

	Quartz Wt. %	Kieselguhr Wt. %
Chemical Analysis		
SiO_2	99.2	90.9
Al_2O_3	0.3	4.6
Fe_2O_3	0.3	1.9
CaO	0.1	1.4
MgO	0.1	0.4
Ignition loss	....	0.3
Undetermined	....	0.5
	100.0	100.0
Physical Analysis		
Specific gravity (H_2O=1.00)	2.65	2.25
Appearance	Uniform, crystalline	Multishaped, amorphous
Porosity	0.371	0.856

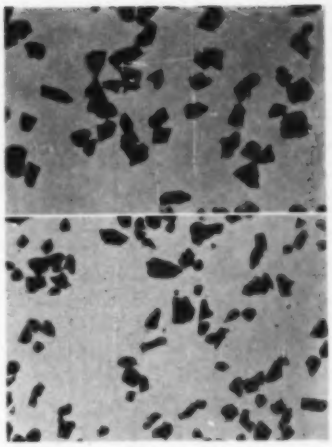


Fig. 6 (top). 2-3 micron quartz (×1400).
One centimeter equals 7.2μ.

Fig. 7 (bottom). 1-2 micron quartz (×1400).
One centimeter equals 7.2μ.

the average of the two runs less the time for 1 cc. of water to flow through the cloth and precoat alone was used as the reciprocal rate of flow in the calculations. The temperature of the water was recorded and the volume of the cake (less that of the precoat) was noted by a direct reading of the burette. The thickness of the cake was calculated from the volume of the cake and the cross-sectional area of the tube.

Experimental Data. Filtration and permeability tests were made on each of the separated samples and the "As Is" sample of quartz, and on mixtures of 25 wt.% of diatomaceous earth—75% quartz; 50% of each; and 25% quartz—75% diatomaceous earth. The experimental data are tabulated in Tables 5 and 7 of the Appendix.

Calculated Results

The average specific resistances to filtration were calculated from Equation (6) on a weight basis and Equation (5) on a volume basis. Average specific resistances from the permeability tests were calculated from Equation (9) on a weight basis and Equation (8) on a volume basis. A complete sample calculation for a typical test is included in the Appendix.

Calculated results are summarized in Table 2 of the text and presented in detail in Tables 6 and 8 of the Appendix. The average porosities, surface areas, and specific resistances are listed in addition to the average percentage deviation from the mean of the latter.

Comment

Specific resistances are presented on both weight and volume bases. The advantage of using r_w, the resistance per unit weight, is that it makes the calculations of the filtration data completely independent of permeability data, i.e., it is not necessary to know the porosity of the cake in order to calculate r_w. On the other hand, the resistance based upon a unit volume of cake, r_v, best illustrates the effect of filter aids in increasing the porosity and decreasing the resistance to flow.

Estimated Accuracy. Duplicate tests were made on all filtrations to determine their precision. The average precision for 56 filtration tests was 4.63% for r_{fw} and 4.53% for r_{fv}. The deviation from the mean is shown in Figure 9 on both the weight and volume bases. Errors within the filtration tests are most likely due to agitation in the pressure vessels. This particular problem is important, for inadequate agitation leads to settling and an uneven formation of the filter cake. Too much agitation could lead to erosion of the particles and increased resistance.

The average precision within the 51 permeability tests is 1.65% for r_{pw} and 1.79% for r_{pv}. The greatest source of error in the permeability tests is the determination of the true cake volume. The surface of the cake is not always horizontal. This would occur if any nonuniform settling took place during the formation of the cake.

The resistance to flow calculated from permeability tests compares favorably with the resistances based upon filtration tests. The average deviation of r_{fw} and r_{pw} from their average is 3.62%, which is less than the average precision of the filtration tests. Since the filtrate volume collected at any time is inversely proportional to the square root of the average

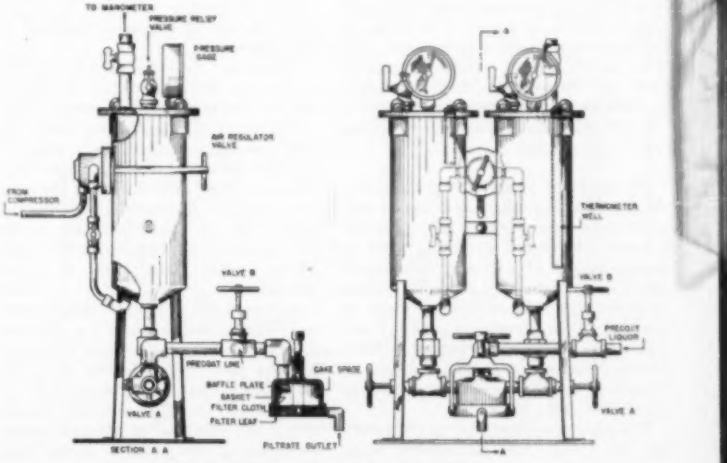


Fig. 8. Drawing of filtration apparatus.

TABLE 2—SUMMARY OF CALCULATED RESULTS

SiO_2 μ	Wt. % SiO_2	Wt. % *DE**	ϵ Average Porosity	S_o Average Surface Area of Particles sq.cm./cc.	r_{fv} Average Filtration Cake Resistance per Unit Volume (sq.sec./cc.) $\times 10^{-6}$	r_{pv} Average Permeability Cake Resistance per Unit Volume (sq.sec./cc.) $\times 10^{-6}$	Average Per Cent Deviation of r_{fv} and r_{pv} from the Mean	r_{fw} Average Filtration Cake Resistance per Unit Wt. (sq.sec./g.) $\times 10^{-6}$	r_{pw} Average Permeability Cake Resistance per Unit Wt. (sq.sec./g.) $\times 10^{-6}$	Average Per Cent Deviation of r_{fw} and r_{pw} from the Mean
As Is	100	0	0.3710	19175	14.52	13.08	5.22	8.645	7.83	4.94
	75	25	0.6625	42000	3.50	3.475	0.36	4.155	4.04	1.40
	50	50	0.7760	50000	1.364	1.152	6.44	2.485	2.103	8.32
	25	75	0.8253	64500	1.149	1.108	1.81	2.795	2.705	3.27
(1-2)	100	0	0.4610	202900	622.5	652.0	2.32	437.5	457.0	2.25
	75	25	0.5975	147250	84.3	72.2	7.66	81.65	70.45	7.87
	50	50	0.7325	150500	21.0	20.6	0.96	32.02	31.45	0.86
	25	75	0.8135	109050	3.98	3.89	8.21	9.055	7.69	8.10
(2-3)	100	0	0.5620	60900	20.25	16.57	9.99	17.45	14.31	9.87
	75	25	0.6465	68200	10.86	10.48	1.78	12.01	11.625	1.63
	50	50	0.7370	72950	4.70	4.34	3.75	7.29	6.725	4.05
	25	75	0.8153	79900	2.075	1.95	3.09	4.715	4.475	2.61
(3-5)	100	0	0.5560	43500	11.02	10.01	4.89	9.37	8.42	5.33
	75	25	0.7005	57550	4.30	4.265	0.41	5.75	5.57	1.59
	50	50	0.7910	66400	1.975	1.90	1.93	3.85	3.69	2.12
	25	75	0.8295	74300	1.435	1.191	9.30	3.585	2.985	9.14
(5-10)	100	0	0.6030	26500	2.52	2.403	2.87	2.40	2.275	2.67
	75	25	0.7170	37550	1.565	1.701	4.17	2.37	2.37	4.41
	50	50	0.7960	50900	1.085	1.127	1.90	2.175	2.25	1.69
	25	75	0.8330	66900	1.095	0.987	5.19	2.79	2.51	5.28
(10-20)	100	0	0.5810	12455	0.701	0.708	0.04	0.632	0.636	0.04
	75	25	0.7365	29600	0.786	0.800	0.88	1.195	1.19	0.21
	50	50	0.7990	46800	0.876	0.908	1.79	1.78	1.845	1.79
	25	75	0.8330	61050	0.910	0.983	3.85	2.32	2.51	4.11
.....	0	100	0.8527	76450	1.067	0.991	3.59	3.167	2.97	3.52

* *DE* refers to diatomaceous earth.

resistance, the error in predicting the filtrate volume from permeability data would be not greater than that occurring in experimental filtration tests.

Filtration Tests. The variables affecting filtration are controlled easier with the bomb filter press than with any other filtration equipment. Unpublished results obtained in the Dicalite Div. Laboratory have shown that the bomb filter press is an accurate laboratory instrument for predicting plant-scale filtration. The present experimental tests were made in duplicate, and it is believed that their accuracy equals their precision, and is well within usual design limitations.

Most of the former work on filtration was done with plant-scale equipment and large volumes of slurry. Variations in pressure drop, solids concentration, and temperature caused erroneous results. Data are not available in the literature to indicate the precision or accuracy of the previous data because duplicate runs were not reported.

Permeability Tests. The permeability test used in the present study has several advantages over other test methods. Carman (*5*) used a method in which a known weight of dry solids was introduced into a cylinder and gently tapped until the dry cake settled as much as possible. Then a water permeability test was made. Although he seemed to have obtained reasonable results, his method is open to the objection that channeling could easily take place.

Pechukas and Gage (*10*) in commenting on various air permeability tests pointed out that it is necessary to pack the powder tightly in the test cylinder in order to prevent channeling. Comparative tests made on diatomaceous earth in the present study show that the calculation of surface area by air permeability tests agrees with that calculated by the water permeability tests, but that the method using air requires more packing to prevent channeling and therefore results in decreased porosity. Table 3 gives the results of these tests.

The air permeability test is useful in determining surface area but cannot be used by itself for obtaining the average filtration resistance because of the inherent difference in porosity. Even on a weight basis the resistance from the air permeability test is more than three times as great as the resistance from the water permeability test. This is due entirely to the low porosity obtained in the former test.

These data show the same permeability with air and water when the cake is put on the same porosity basis. Ruth (*12*) found that for precipitated and dried calcium carbonate, the permeability with air was 3.07 times larger than the value found with water, on the same porosity basis. His results might be explained by the possibility that a cake formed by dry packing will not be completely wetted when water is passed through it.

The plausibility of the present permeability method as a test for filtration resistance is apparent when it is realized that the cake formed in this test is of the same nature as that formed in an actual filtration. This eliminates channeling and provides an accurate means of obtaining the porosity of the filter cake.

Effect of Precoat. A precoat of 10 lb./100 sq.ft. of filter area of diatomaceous earth was applied on most of the filtrations. Its purpose was to present a uniform porous, nonpenetrable filter septum for all tests. The method of applying the precoat precludes a high degree of accuracy which accounts for most of the minor deviations in R_i the initial or septum resistance. For many of the runs, the precoat was applied in heavier amounts, especially for those containing high percentages of fine quartz. Generally, the cake resistance was found to be independent of the septum resistance, although there is some indication that a high initial resistance yields higher cake resistance. In any event, if too heavy a precoat is applied, it usually takes longer for the cake resistance to become noticeable.

This is illustrated in Figure 10. Three filtrations were made with the same material, a mixture of 25% diatomaceous earth and 75% of the 5-10μ silica. The filtrations differed only in the amount of precoat applied. Run A had no precoat, B had a 10-lb./100-sq.ft. precoat, and C had a precoat of 15 lb./100 sq.ft. The plot of θ/V against V is a straight line for all the data of B, whereas about half the runs were required to smooth out the data for A and C. The precoat resistance was of such a magnitude in C that it overshadowed the cake resistance for much of the run. If C had been carried out for a longer time, more points might have shown the slope to be equal to that of B.

Likewise, zero precoat results in unusually high initial flow and often leads to plugging of the filter cloth. The excessively high initial flow is due to the

TABLE 3.—COMPARISON BETWEEN AIR PERMEABILITY AND WATER PERMEABILITY TESTS FOR DIATOMACEOUS EARTH

	Air Permeability	Water Permeability
Weight of sample—g.	0.4876	2.0
Density of sample—g./cc.	2.23	2.25
Volume of cake—cc.	0.756	5.90
Temperature—° C.	21.0	22.5
Viscosity—poises	.000185	.00947
Reciprocal rate—sec./cc.	8.67	27.3
Pressure drop through cake—g./sq.cm.	704.	704.
Cross-sectional area of cylinder—sq.cm.	.378	1.77
Thickness of cake—cm.	2.0	3.33
Porosity of cake	.714	.849
Surface area of cake—sq.cm./cc. of solids	74600.	74300.
Resistance of cake—sq.sec./cc. of cake	6.37×10^6	1.077×10^6
Resistance of cake—sq.sec./g. solids	9.89×10^6	2.17×10^6

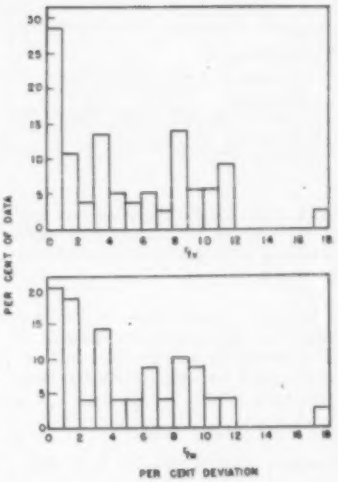


Fig. 9. Precision of filtration data.

inability of the cloth to retain the solids, resulting in less resistance to flow but also in poorer clarity. This is illustrated in Figure 10 by run A. The early points in this run were above the line, and the intercept was negative, which indicates too low an initial resistance. The time-flow data for these filtrations are given in Table 4.

Several of the runs with precoats had negative intercepts, which show that those runs had insufficient precoats and that some of the solids might have passed through the thin precoat. This tendency was greatest for those runs in which diatomaceous earth was not present in the slurry.

Surface Area. The surface areas were calculated from permeability data by Equation (10). It is logical to assume that the surface areas of mixtures of particles should be additive if no attrition occurred. Figure 11 shows this to be the case, for when S_o, the specific surface area in sq. meters per cc. of powder, is plotted against the volume percentage of diatomaceous earth, a straight line generally results. The data fit this linear relationship within ten per cent with only two exceptions.

The calculation of surface area may be made by several other methods, notably nitrogen or other gaseous adsorption methods, and microscopic particle counts. The latter method is not suitable for these systems because of the odd shapes of the diatomaceous earth particles. The gas adsorption method as outlined by Emmett (*6*) probably gives more precise values for surface area though it is more complicated. However, the surface area in the present calculations is used as a measure of the frictional resistance to flow, and the permeability method gives sufficiently accurate and reproducible results. Present results are within the eight per cent margin which Carman (*5*) claims to be the accuracy of the permeability test. Anderson, McCartney, Hall and Hofer (*1*) reported surface areas determined from the nitrogen adsorption test on the same grade of diatomaceous earth as used in these experiments as 7.88 sq.m./cc. This compares quite favorably with 7.65 sq.m./cc., the average value obtained from this permeability method.

Porosity. Figure 12 shows the porosity plotted against the weight per cent of diatomaceous earth in the solid mixture. A porosity of 0.371 for the unseparated quartz is in agreement with the values obtained for the random packing of sand beds, 0.36–0.45 (*4*). The diatomaceous earth has a high porosity (0.856) because of its shape. Mixtures of these materials result in porosities intermediate in value between the two. The rate of porosity increase is greatest for mixtures of unseparated quartz and diatomaceous earth containing up to fifty per cent of the latter. Above this figure, the rate of increase drops rapidly. This helps in explaining why relatively small amounts of filter aid often produce such marked improvement in the filtration properties of difficult filterable systems. When this increase in porosity is combined with a decrease in surface area, as is the case with mixtures of the 1-2μ cut, the improvement in filtration properties is the greatest.

Average Specific Resistances. A graphical presentation of the data for the average specific resistances is given in Figures 13 and 14. In Figure 13, the resistance/g. of 1 to 1 and 3 to 1 mixtures of "As Is" quartz and diatomaceous earth is less than the resistance of either. This is explainable by the fact that the particle-size distribution of these mixtures is such that the porosity and the porosity function $\epsilon^3/(1-\epsilon)^2$ approach that of the diatomaceous earth while the surface area, being additive, is considerably less. This unusual circumstance also occurs in mixtures of the 5-10μ quartz and diatomaceous earth.

Figure 14 shows that when the resistances are calculated on a volume basis, the addition of diatomaceous earth generally decreases the average specific resistance. Even though the surface area and the frictional resistance are greater for the diatomaceous earth than for all quartz other than the 1–2μ range, the resistance per unit volume of cake is less because of the marked increase in the porosity of the cake. For the 10–20μ quartz, the increase in porosity does not

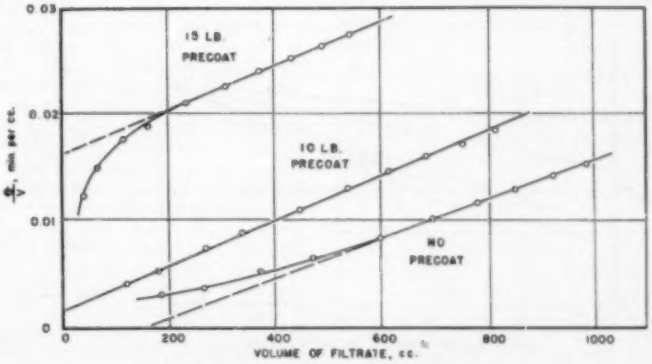


Fig. 10. Effect of precoat on filtration data.

TABLE 4.—TIME-FLOW DATA ILLUSTRATING EFFECT OF PRECOAT

Time—min.	0.5	1	2	3	5	7	9	11	13	15
Filtrate Volume—cc.										
A—No precoat	187	267	375	475	602	700	762	856	928	990
B—10 lb./100 sq.ft. precoat	117	181	269	337	450	538	617	689	756	818
C—15 lb./100 sq.ft. precoat	40	65	112	160	236	307	374	435	493	543

balance the increase in surface area, and so the addition of diatomaceous earth results in an increased average specific resistance.

Influence of the Particle Size and Shape. If the particles are assumed to be spherical, an average diameter may be calculated from the surface area data, since for a sphere,

$$d = 6/S_o \qquad (12)$$

Kozeny's equation may then be written:

$$r_{pw} = \frac{0.184(1-\epsilon)}{\epsilon^3 \rho' d^2} \qquad (13)$$

If one of the more conventional means of obtaining an average diameter, i.e., microscopic slides, a weighted average screen diameter, or from a sedimentation curve, is used in Equation (13), the calculated value of r_{fw} would be considerably in error. Considering the 1–2μ quartz, an average particle diameter would be nearly 1.5μ from both photomicrographs (Fig. 7) and a sedimentation curve. When this value of d is used in Equation (13), r_{fw} is calculated to be 17.0×10^6 sq.sec./g., while the actual filtration resistance was measured as $457. \times 10^6$ sq.sec./g. The diameter calculated from the surface area by the use of Equation (12) is 0.296μ, and the substitution of this value for d into Equation (13) gives a value of r_{fw} equal to 438×10^6 sq.sec./g.

This illustrates the fact that the resistance to flow is a function of the surface area instead of the diameter, and that unless the particles are spherical, the diameter obtained from any of the conventional methods would give incorrect results when used in Equation (13) to calculate the resistance to flow.

To make use of Equation (13) a a shape factor would have to be introduced, which relates the actual particle shape to that of a sphere. By definition, from Equation (12)

$$f = 6/dS_o \qquad (14)$$

and Equation (13) becomes

$$r_{pw} = \frac{0.184(1-\epsilon)}{\epsilon^3 \rho' f^2 d^2} \qquad (15)$$

Values of the shape factor f can be calculated from the present data with any meaning only for the runs made on the separated quartz fractions. To illustrate, using an arithmetic average diameter for the particles and the surface areas reported in Table 3:

Particle Size, μ	Shape Factor f, by Eq. (14)	f^2 to be Used in Eq. (15)
1-2	0.197	0.0388
2-3	0.394	0.1552
3-5	0.345	0.1190
5-10	0.301	0.0906
10-20	0.322	0.1036

The shape factor to be used in Equation (15) is seen to follow a random pattern. A single value of f cannot be used to satisfy all the present data. There is no conclusive evidence to show that f should have the same value for different particle sizes, either in the present or in previous work.

It may be noted that the smallest value of f is for the smallest size of quartz, the 1–2μ cut. Ruth (*12*) noted the same phenomenon, in that the shape factor became smaller as the particle size decreased, for both chemical precipitates and finely ground mineral particles sized by sedimentation. It is entirely possible that Kozeny's equation might not apply to fine particles. Carman (*4*) indicated

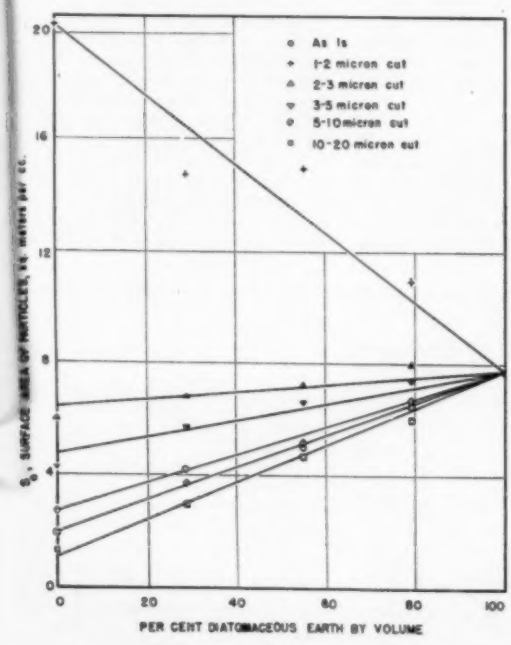

As Is
1-2 micron cut
2-3 micron cut
3-5 micron cut
5-10 micron cut
10-20 micron cut
S_o, SURFACE AREA OF PARTICLES, SQ. METERS PER CC.
PER CENT DIATOMACEOUS EARTH BY VOLUME

Fig. 11. Effect of composition on surface area.

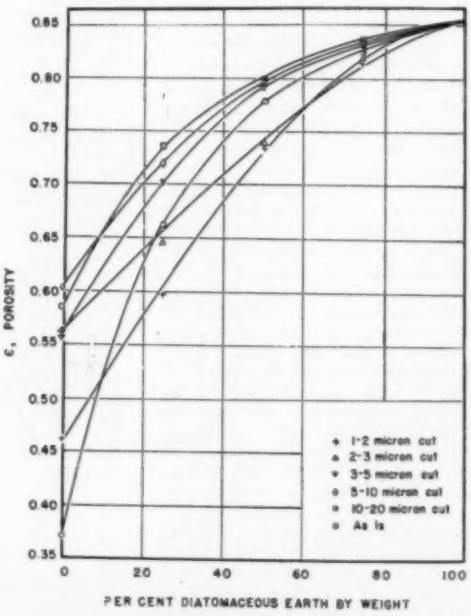


Fig. 12. Effect of composition on porosity.

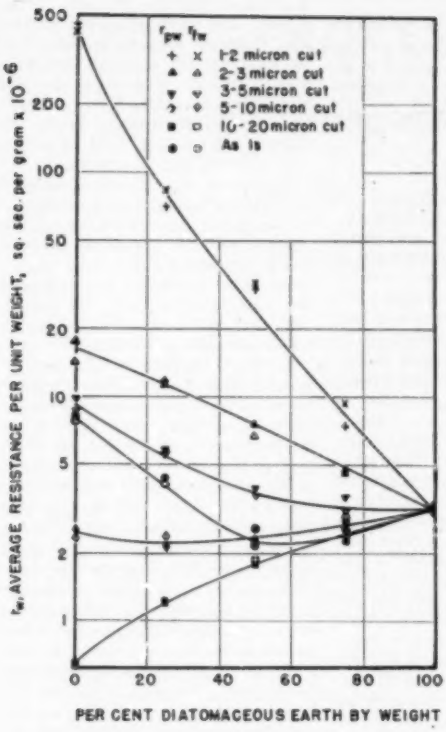

r_{pv} r_{fv}
1-2 micron cut
2-3 micron cut
3-5 micron cut
5-10 micron cut
10-20 micron cut
As is
r_w, AVERAGE RESISTANCE PER UNIT WEIGHT, sq. sec. per gram x 10^{-6}
PER CENT DIATOMACEOUS EARTH BY WEIGHT

Fig. 13. Effect of composition on specific resistance (wt. basis).

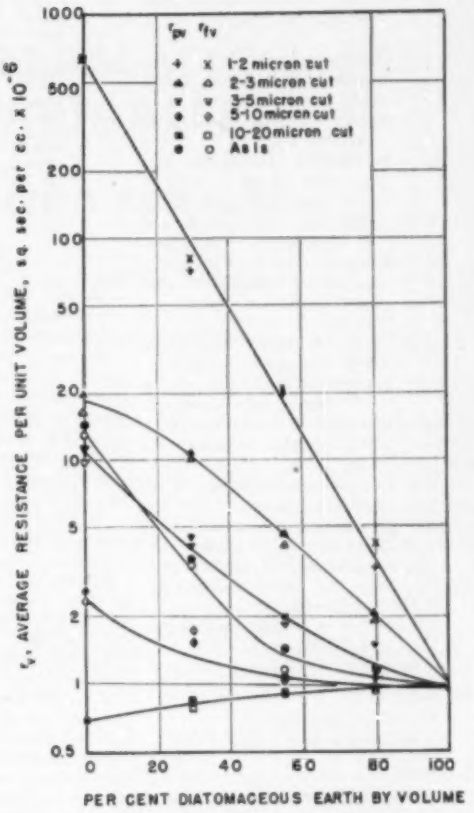

r_{pv} r_{fv}
1-2 micron cut
2-3 micron cut
3-5 micron cut
5-10 micron cut
10-20 micron cut
As is
r_v, AVERAGE RESISTANCE PER UNIT VOLUME, sq. sec. per cc. x 10^{-6}
PER CENT DIATOMACEOUS EARTH BY VOLUME

Fig. 14. Effect of composition on specific resistance (vol. basis).

that Kozeny's equation holds good for effective diameters (as defined by Eq. (12)) as small as 2.7μ. The lower limit of applicability of this equation is not clearly defined, and the present data are not sufficient to clarify the issue.

The most serious objection to the use of shape factors and equivalent diameters is the inability to obtain a reasonable value of the effective diameter for particles of widely different shapes, such as diatomaceous earth (Fig. 1). Therefore, it is believed easier to use Kozeny's equation with the surface area instead of the particle diameter and shape factor as a parameter of resistance.

Conclusions

The original data reported in this paper on the essentially noncompressible mixtures of quartz and diatomaceous earth confirm the equivalence of specific filtration resistance and specific permeability resistance. A simple permeability test is completely adequate for predicting filtration characteristics of the same system.

Particle diameters obtained by conventional means, such as from microscopic slides, average screen analyses, and sedimentation curves, can not be used directly in the Kozeny equation for accurate results, without the inclusion of a proper shape factor. Generally, it is easier to use surface area instead of the diameter as a parameter.

Different amounts of precoat appear to have little or no effect upon the specific filtration resistance, although with either too little or too much precoat, longer times are required for the cake or bed resistance to become noticeable.

Surface areas calculated from permeability tests are found to be additive on a volume basis for the various mixtures. Both air and water permeability tests give similar results for the calculation of surface area, but an air permeability test cannot be used to calculate the specific resistance to filtration because of porosity errors.

It is the marked increase in porosity that is responsible for the improved flow rates of systems in which diatomaceous earth is used as a filter aid.

Acknowledgment

The authors wish to thank the Dicalite Div. for the materials and the bomb filter press used in these experiments.

Notation

A = cross-sectional area of the particle bed, sq.cm.

b = slope of constant pressure filtration line, defined in Equation (5), of net dimensions sec./cm.^{6}

c = weight of solids per unit volume of filtrate, g./cc.

D = average diameter of particles, defined in Equation (11), cm.

d = effective diameter of particles, defined in Equation (12), cm.

f = surface or shape factor, no units

g_c = gravitational conversion factor, taken as 980 (g. mass × cm.)/g. force × sq.sec.)

K = permeability coefficient, defined in Equation (7), cc./sq.sec.

L = thickness of particle bed, cm.

P = total pressure difference across particle bed and septum, g./sq.cm.

R = initial or septum resistance/unit area, sq.sec./sq.cm.

r_v = average specific resistance of a unit cube of cake, sq.sec./cc.

r_w = average specific resistance of a unit weight of cake, sq. sec./g.

S_o = surface area/unit volume of solids, sq.cm./cc.

t = temperature of filtrate, ° C.

u = linear velocity of particles, in Equation (11), cm./sec.

V = volume of filtrate collected, cc.

V' = volume of cake, cc.

v = volume of cake per unit volume of filtrate, cc./cc.

W = weight of solids in the cake, g.

SUBSCRIPTS:

f = refers to filtration

p = refers to permeability

GREEK:

ϵ = porosity, or volume of pore space/volume of granular bed, cc./cc.

θ = time of filtration, sec.

μ = viscosity of filtrate, poises

ρ = density of filtrate, g./cc.

ρ' = true density of the solids. g./cc.

Literature Cited

1. Anderson, R. B., McCartney, J. T., Hall, W. K., and Hofer, L. J. E., *Ind. Eng. Chem.*, **39**, 1618 (1947).
2. Brownell, L. E., and Katz, D. L., *Chem. Eng. Progress*, **43**, 537, 601, 703 (1947).
3. Carman, P. C., *J. Soc. Chem. Ind.*, **57**, 225-T (1938).
4. Carman, P. C., *Trans. Inst. Chem. Engrs. (London)*, **16**, 168 (1938).
5. Carman, P. C., *Ind. Eng. Chem.*, **31**, 1047 (1939).
6. Emmett, P. H., *Ind. Eng. Chem.*, **37**, 639 (1945).
7. Fair, G. M., and Hatch, L. P., *J. Am. Water Works Assoc.*, **25**, 1551 (1933).
8. "Instruction Manual for Bomb Filter," Technical Department, The Dicalite Div., Los Angeles, Calif., 24 pp. (1945).
9. Kozeny, J., Sitzber. *Akad. Wiss. Wien, Abt. IIa*, **136**, 271 (1927).
10. Pechukas, A., and Gage, F. W., *Ind. Eng. Chem., Anal. Ed.*, **18**, 370 (1946).
11. Perry, J. H. (ed.), "Chemical Engineers' Handbook," McGraw-Hill Book Co., New York, N. Y., 2nd ed., p. 1654 (1941).
12. Ruth, B. F., *Ind. Eng. Chem.*, **38**, 564 (1946).
13. Walas, S. M., *Trans. Am. Inst. Chem. Engrs.*, **42**, 783 (1946).
14. Walker, W. H., Lewis, W. K., McAdams, W. H., and Gilliland, E. R., "Principles of Chemical Engineering," McGraw-Hill Book Co., New York, N. Y., 3rd ed., p. 346 (1937).

Discussion

Z. G. Deutsch (Deutsch & Loonan, New York, N. Y.): I am not sure I understand the authors' presentation of how they determined surface area. I gather it was done by calculation using two equations which appear to have been based on postulates or assumptions of uncertain validity. Were these mathematical methods checked by direct measurement, using molecular adsorption or the like?

E. H. Hoffing: The method of calculating the surface area from permeability data, has been verified by Carman and many other workers on systems of particles of known dimensions. For some systems, excellent comparable results were obtained in the laboratory between this method and the method using nitrogen adsorption developed by Emmett and others. However the surface area is merely a measure of friction resistance which the permeable bed offers to the fluid. It may not be the total surface area; if the surface is of a highly irregular nature, it contains many pores, and part of the surface may not come in contact with the fluid, and therefore offers no frictional resistance to the fluid.

M. A. Leo (Exchange Orange Products Co., Ontario, Calif.): Does your method apply to compressible systems?

E. H. Hoffing: It is true that the materials which were used are generally classified as incompressible. A great deal of difficulty is encountered when compressible systems are used. Most solids which make up the compressible cake are of a gelatinous nature and have a tendency to fill up the pores of the cloth or the filter cake. In a permeability test on such a system, immediately after the initial surge takes place, all flow ceases since the cloth or filter cake becomes completely plugged. Therefore, it is almost impossible to get reliable data on the total volume of the filter cake. Fortunately, when systems of this nature are encountered in industrial practice, diatomaceous silica or some other type of filter aid is used to make the system relatively incompressible, in which case these data most likely would apply.

C. G. Lindquist (Stanford University, Stanford, Calif.): I might answer the gentleman's question in part. In connection with filtration research that has been carried on at Stanford, we have worked with semicompressible materials and Kozeny's equation certainly holds in form for the material with which we've worked. Expressing the compressibility as a pressure exponent, in the manner of Walker, Lewis, McAdams, and Gilliland, we have gone up to a little less than five-tenths.

In the case of needle-like particles, do you have difficulty with nonuniformity of results? In other words, do you have cakes of different porosities and different resistances for the same material when your conditions are supposedly the same? We've had some difficulty with that, and I wonder if you've had the same experience or not?

E. H. Hoffing: It is true that it is often difficult to get reproducible results when such a system is used for running permeability tests. In these tests I weighed out a small amount of the sample, dispersed it in water and filtered it through a cloth in a section of a 50-cc. burette. The volume of the cake could be measured directly, and from the weight and specific gravity of the material, the porosity could be determined. The cake was used for permeability tests; the advantage is that the cake itself is actually a filter cake, and if conducted under the same pressure conditions, excellent reproducible results will be obtained. The most critical variable is the pressure, because in almost every case, the porosity of the filter cake is a function of the pressure.

J. W. Kenny (Great Lakes Carbon Corp., Los Angeles, Calif.: Can you describe in a little more detail the difference between filtration on bomb filter test and in the permeability test?

E. H. Hoffing: The method that is used for the permeability test is to form a cake under filtration conditions, and then once the cake is formed, to pass clear water through it. Using D'Arcy's law, I could calculate the resistance to permeability, which compares favorably with that of filtration. The advantage of this method over other methods shown in the literature for permeability tests, is that if any channeling were to take place, it would cease immediately because of the fact that the filtration is continually taking place, and the solids would immediately plug up the channel. The cake would be uniform. In other methods described in the literature, such as forming a cake by tamping or packing, differences may be possible due to this channeling effect.

(Presented at Los Angeles (Calif.) Meeting.)

GENERALIZED CORRELATION OF PROCESS VARIABLES

MULTICOMPONENT SOLVENT EXTRACTION

CLYDE BERG, MARTIN MANDERS, and ROBERT SWITZER

Union Oil Company of California, Los Angeles, California

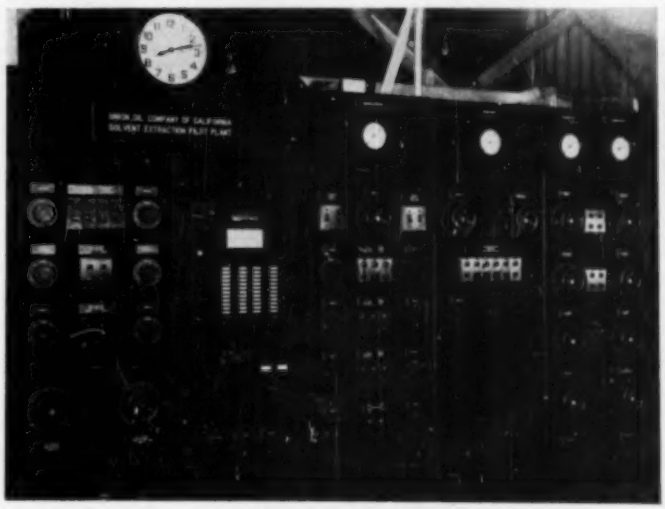
Use of the overlap coefficient is developed as a basic factor in the correlation of the process variables of multicomponent solvent extraction. This correlation generalizes the relationship between the reflux ratio and number of stages of extraction operation required to make a product of a given specification. By this method the optimum design of a given solvent extraction installation can be determined by the economic balance between solvent circulation, number of stages, and the quality of raffinate and extract. It is also of value in determining the effect of changes to existing facilities, such as that which might be brought about by adding an additional extraction tower to an existing plant.

The correlation is applied to pilot plant data on the furfural extraction of SAE 40 dewaxed lubricating oil distillate from Los Angeles Basin crude. Fundamental extraction characteristics for the pilot plant extraction tower are developed from water extraction of the system methyl ethyl ketone-naphtha.

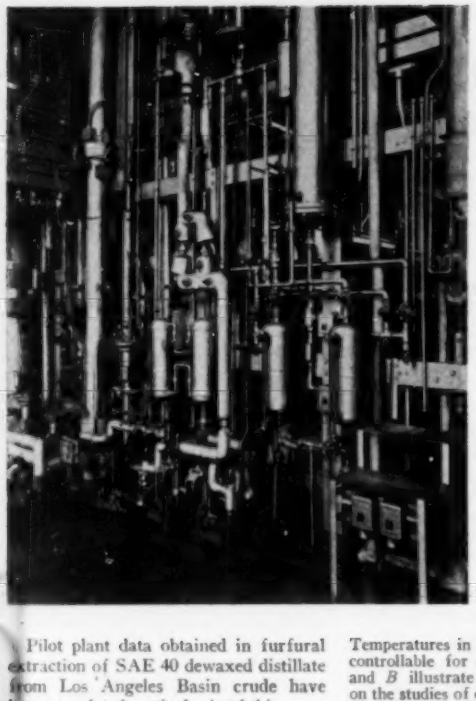
THE designer of a commercial extraction unit is faced with the problem of determining the number of extraction stages and the amount of reflux to be used in order to obtain suitable yield of specified quality raffinate. From pilot plant data it is possible to evaluate the variation in yield with reflux ratio. However, the number of stages is usually held constant, and the effect of changing the number of stages instead of reflux ratio is frequently not available. A wide range of stage numbers is normally available to the plant designer and in the case of an existing plant the number of stages in the commercial tower may differ from the pilot unit. For the most effective use of pilot plant data and these design problems, it is important that a correlation relating stage number and other process variables in extraction operation be available.

Most previous attacks on this problem have simplified the extraction of a multicomponent feed stock to one involving the separation of two or three components by the solvent. Hunter and Nash have published a number of articles outlining this type of approach (*8, 11-13*). This method of analysis is inadequate for the handling of stocks containing a wide range of components as illustrated by the commercial refining of lubricating oil which consists of nearly an infinite number of components. The true relationship between yield and quality and process variables can only be handled by recognizing the existence of this complex mixture in the feed. A useful correlation must be capable of handling and supplementing pilot plant data.

As a new approach to this problem, the overlap coefficient correlations developed by Meyer (*15*) for use in the distillation of complex hydrocarbon systems have been extended to handle operations involved in the extraction of multicomponent stocks. In this correlation the number of theoretical stages and reflux ratios are related to a single function called the overlap coefficient which is a numerical representation of the effectiveness of the operation being carried out in the extraction tower. In this work the overlap coefficient charts have been extended to cover a range of reflux ratio from infinity to 0.25 and stage numbers from unity up to 30.



View of panelboard.
Solvent extraction pilot plant.



General view of equipment. Solvent extraction pilot plant.

Pilot plant data obtained in furfural extraction of SAE 40 dewaxed distillate from Los Angeles Basin crude have been correlated on the basis of this overlap coefficient, directly combining the effects of reflux ratio, number of stages, yield and quality, thereby presenting a completely generalized set of data describing solvent extraction of a multicomponent stock.

Experimental Study

Pilot Plant Apparatus and Operation.—The extraction tower employed in these studies was packed with 37 ft. of 8-mm. glass Raschig rings in five sections. The top three sections, totaling 23 ft., were of 2-in. Schedule 40 pipe. The lower two sections, totaling 14 ft., were of 3-in. Schedule 40 pipe. Each section was insulated and provided with nichrome heating elements. Temperatures in the tower were separately controllable for each section. Figures *A* and *B* illustrate the equipment employed on the studies of extraction of methyl-ethyl-ketone (*MEK*)-naphtha employing water as a solvent and the flow diagram is given in Figure 1. The *MEK*-naphtha mixture was fed to the bottom of the extraction column at a point just above the liquid interphase. Water entered the top of the column through a distributing head. Interphase level between naphtha and water phases was controlled by a conductivity instrument with the water phase being released automatically into the solvent recovery column.

In the recovery column *MEK* was distilled overhead into a gravity separator into which all existing water was returned by gravity back to the distillation column. Water, free of *MEK*, was produced from the base of the distillation column, cooled and continuously pumped back to the storage tank. The naphtha produced overhead as raffinate from the extraction column was released through a back-pressure controller and collected in a second storage tank. Feed rates were controlled by needle valves on the discharge of calibrated rotameters. Nitrogen pressure on solvent and feed storage tanks maintained constant pressure drop across the rotameter rate valves. The solvent and feed lines were arranged with an electric preheater which made possible the addition of solvent and feed at the desired temperatures. Sampling outlets were provided in the extraction column so samples could be taken of the continuous phase at various points in the column and at both ends of the column. The sampling points are shown in Figure 1. The extraction column was controlled by determining the refractive index of material drawn from the sampled points. These samples were withdrawn every 2 hr. and retained so that composite samples could be analyzed. In most cases samples for a 24-hr. run were composited to get truly representative results. Lower concentrations of *MEK* were determined by reaction of hydroxylamine hydrochloride with the ketone and titration of the acid produced with dilute caustic.

Equilibrium Data for System MEK-Water-Naphtha. The equilibrium data for the system *MEK*-water-naphtha are given in Figure 2. Characteristics of the naphtha used in these studies are given in Table 1.

Mutual solubility boundaries were determined in a manner similar to that of Othmer, White and Trueger (*20*). The tie line or equilibrium data were determined by making mixtures of the three components, agitating and allowing the two phases to come to equilibrium at 80° in a constant temperature bath.

Data and Results. In the operation of the pilot plant, two different conditions were used. One employed the water phase as the dispersed phase and the other employed the naphtha phase as the dispersed phase. This was accomplished by locating the level controller at the bottom when employing water as the dispersed phase and at the top when employing naphtha as the dispersed phase. The theoretical stage heights for the various runs were determined by the method of Varteressian and Fenske (*26*) and are presented in Table 2. An average of the concentration ratio *H* for each section is also given in Table 2.

In runs 9, 10, and 11, the packing was treated with quinoline. By chemisorption the quinoline forms an organic layer on the glass Raschig rings, causing them to be wet by the gasoline phase rather than the water phase. This provided data on the wetting effects on the packed column. Slightly more efficient operation was obtained when the naphtha phase wet the packing.

Stage heights obtained indicate efficient

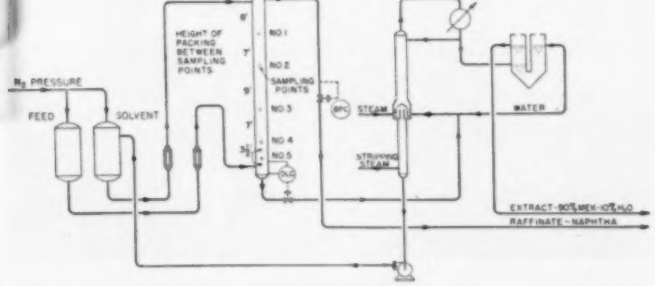


Fig. 1. Process flow diagram extraction pilot plant for water-naphtha-mek system.

TABLE 1

PROPERTIES OF NAPHTHA

Engler Distillation	
Initial	142°F.
10%	193°F.
50%	228°F.
90%	268°F.
Max.	307°F.
API Gravity at 60°F.	59.8
Mixed Acid Solubility[3]	1.0% by volume
Olefins (by Br2No2)	0% by volume
C.F.S. Aniline Point	53.6°C.

operation when the solvent was employed as the dispersed phase. A considerable reduction in effective contacting occurred when the naphtha was employed as the dispersed phase.

Equipment Employed in Pilot Plant Extraction of SAE 40 Dewaxed Lubricating Oil. The process flow sheet for the extraction pilot plant as set up for operation on furfural extraction of SAE 40 dewaxed lubricating oil distillate from the Los Angeles Basin crude is shown in Figure 3. Oil feed was metered by a Milton Roy adjustable stroke pump through an electric preheater into the center of the extraction column. Construction of the column was identical to that outlined for the previous studies on *MEK* extraction.

Solvent feed was pressured through a rotameter to an electric preheater and into the top of the tower. Raffinate overflowed from the top of the tower through a back-pressure controller into the collecting tank. The raffinate contained about 10% dissolved solvent.

An air-operated displacement-type level control located at the base of the unit controlled production of the extract phase to maintain the interphase at this point.

Solvent was recovered from the extract solution by preheating the mixture in a steam exchanger followed by expansion into a cyclone flash chamber held at 20 in. of Hg vacuum. Furfural vapor traveled through a condenser, thence to a manifolded double-tank system. A transfer pump periodically returned the solvent to its feed tank.

The denuded extract which still contained about 5% furfural dropped to the bottom of the cyclone sealing leg where it was picked up by the reflux splitting pump. The liquid level in this sealing leg was controlled by a level controller which started and stopped the pump. The reflux pump was a two-cylinder adjustable stroke Hills-McCanna pump which positively proportioned reflux.

Both extract and raffinate samples were bench-stripped under vacuum to remove their solvent content prior to inspection.

Operation and Results

All runs were made with oil as the continuous phase. Rates of raffinate and extract were taken every hour during operation. After the rates had become uniform, gravities were determined on stripped samples. When a series of samples showed gravities had been reasonably constant, the unit was considered on stream. For all runs a minimum on stream time of 24 hr. was employed.

a. *Oil Solubility.* The bottom tower temperature for each run was selected to give about 20% oil in the extract phase. Other temperatures were selected to give about the same solubility throughout the tower. For the "zero" reflux runs, an induced reflux was created in the lower or reactifying section of the column by decreasing the bottom temperature in order to remove the oil as a 10% solution in the solvent. This solubility was graded to 20% at the oil inlet.

b. *Solvent Ratio.* Solvent requirements for a given run were calculated as follows from the expected yield and reflux ratio utilized: Consider an operation producing 40 parts of raffinate and 60 parts of extract product per 100 parts of feed. If the reflux ratio is five to one, the column reflux is then five times 60 or 300 parts of extract oil. Since the extract production is 60 parts, the quantity of extract leaving the column in the solvent is 300 plus 60 or 360 parts. This is produced as a 20% solution which involves 1440 parts of solvent. The 40 parts of raffinate would dissolve about four parts of solvent giving a total solvent requirement of 1444 volumes, or a solvent to feed ratio of 14.44.

The relative flows of oil in the oil and solvent phases at various reflux ratios may be seen on Figure 4.

The inefficiency of the temperature rejection operation can be seen in the *O/V* (volumes oil up/volumes oil down) variation from zero at the bottom, where the reflux is most needed, to 0.5 at the oil feed.

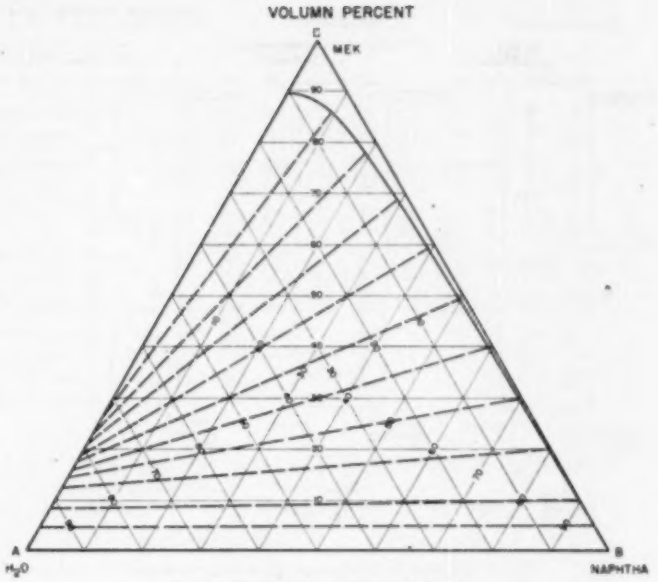


Fig. 2. Equilibrium diagram at 80° F.

Experimental Data. Data for all runs on this feed stock are given in Table 4. Figure 5 presents a plot of the raffinate yields as a function of viscosity index at several reflux ratios. Data in Table 4 were obtained at principal reflux ratios of 5:1, 2:1 and 0.3:1. The curves representing 2:1 and 0.3:1 reflux ratios have been extrapolated in the region of high viscosity index, and these extensions are represented by broken lines.

Correlation of Experimental Data

Evaluation of Stage Numbers in Pilot Plant Extraction. To correlate the data

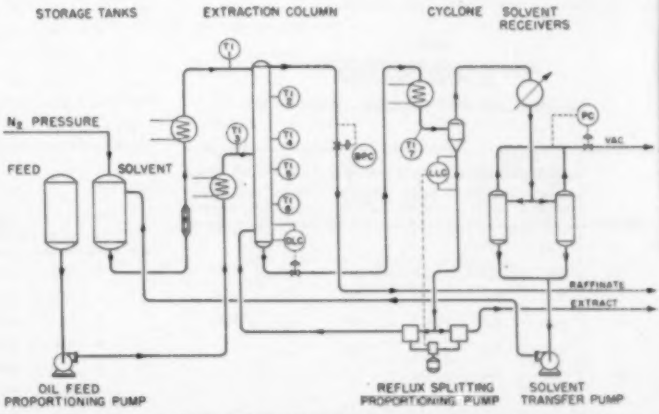


Fig. 3. Process flow diagram extraction pilot plant for lubricating oil extraction.

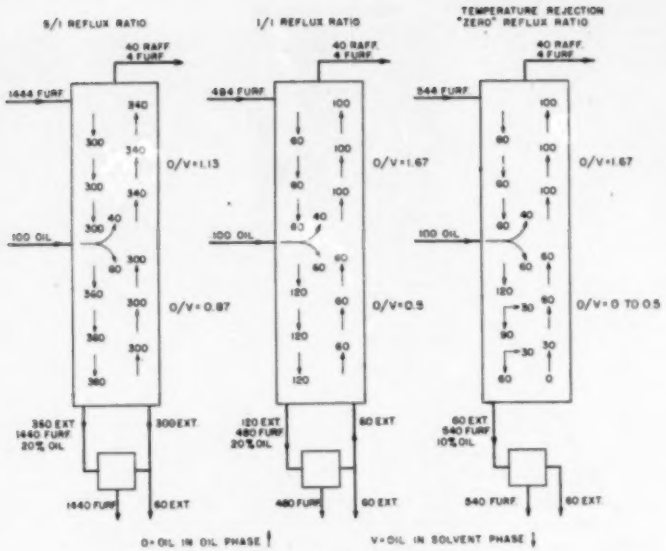


Fig. 4. Oil flow in lubricating oil extraction tower.

on extraction of dewaxed lubricating oil distillate, it was necessary to estimate the effective stage heights in the pilot plant extraction column. For this purpose data on MEK-water-naphtha system were employed. In these correlations the height of one equivalent transfer stage concept was required to permit practical application to multicomponent systems where components cannot be identified individually.

In reviewing the mechanics of dispersed and continuous phase flow through a packed column, the evidence of a number of investigators (*1, 4*) is that the dispersed phase flow through the column is not by two continuous films in countercurrent motion but rather one continuous phase filling the column with a dispersed phase flowing through the packing and rising (or falling) largely in the form of drops. Probably the fundamental difference between spray column operation and packed column operation is the fact that drop diameter is largely controlled by packing size with coalescent effects balancing surface tension effects. Employing the H.E.T.S. concept, analysis of the transfer mechanism parallels gas-liquid contacting in a bubble-cap tray with a single exception of drop sizes being essentially a function of packing characteristics.

The Murphree (*17*) concept of plate efficiency applies in liquid-liquid contacting as well as gas-liquid contacting and is developed from the differential transfer rate given by the following equation:

$$KA(c-c^*)dt = -Vdc \qquad (1)$$

Its integrated form is given by the following relationship:

$$ln\left(1-\frac{c_o-c_f}{c_o-c^*}\right) = -\frac{KAt}{V} \qquad (2)$$

Defining the Murphree efficiency, E_m, as

$$E_m = \frac{c_o-c_f}{c_o-c^*} \qquad (3)$$

the relationship reduces to

$$ln(1-E_m) = -\frac{KAt}{V} \qquad (4)$$

Geddes (*9*) has reduced this equation to a still more fundamental form:

$$ln(1-E_m) = -\frac{3Kt}{r} \qquad (5)$$

For two different liquid-liquid systems, stage lengths of equivalent Murphree efficiency are defined by the following relationship:

$$ln(1-E_m) = -\frac{3K_1t_1}{r_1} = -\frac{3K_2t_2}{r_2} \qquad (6)$$

TABLE 2

STAGE HEIGHTS AND CONCENTRATION RATIO IN THE PILOT PLANT COLUMN

Operation on Water-Methyl Ethyl Ketone-Naphtha System

Run No.	Extract to No. 5 Point h Stage Height ft.	Extract to No. 5 Point K Concentr. Ratio	No. 5 Point to No. 4 Point h Stage Height ft.	No. 5 Point to No. 4 Point K Concentr. Ratio	No. 4 Point to No. 3 Point h Stage Height ft.	No. 4 Point to No. 3 Point K Concentr. Ratio
5	1.45	0.73				
6	6.6	3.3	6.8	3.0	3.6	1.55
7	6.2	3.4	6.1	3.3	3.6	1.82
8	6.9	3.4	6.4	3.3	5.9	2.63
9	5.1	3.3	3.7	2.4		
10	5.5	3.4	4.4	3.0		
11	1.39	0.72				

Run conditions used in these runs are presented in Table 3.

TABLE 3

RATES USED IN EXTRACTION OF METHYL-ETHYL-KETONE

Run No.	Feed	Water	Raff.	Extract	Flow Rates at Bottom Col. sq.ft./hr.sq.ft.: Disp. Phase	Flow Rates at Bottom Col. sq.ft./hr.sq.ft.: Cont. Phase	Disp. Phase	Packing Wetted by
5	1.02	4.0	.25	4.9	12.5	2.7	Water	Water
6	1.10	4.0	.27	4.8	2.9	12.6	Naphtha	Water
7	1.36	4.3	.33	5.4	3.6	14.2	Naphtha	Water
8	1.42	4.0	.35	5.1	3.7	13.2	Naphtha	Water
9	1.02	4.0	.25	4.9	2.7	12.5	Naphtha	Naphtha
10	1.27	4.3	.31	5.3	3.3	13.7	Naphtha	Naphtha
11	1.02	4.0	.25	4.9	12.5	2.7	Water	Naphtha

ANALYTICAL RESULTS IN PILOT PLANT RUNS

Run No.	Cont. Phase	Water Layer, Volume % MEK Extract	Sample Points #3	Sample Points #4	Sample Points #5	Naphtha Layer, Volume % MEK Feed	Samp. Points #3	Samp. Points #4	Raff.
5	Naph.	15.6				73.4	1.04	nil	nil
6	Water	16.7	11.1	4.61	0.027	73.4			nil
7	Water	18.7	13.8	8.81	0.069	73.4			nil
8	Water	20.5	18.3	15.9	3.98	73.4			nil
9	Water	15.6	7.28	1.40	nil	73.4			nil
10	Water	17.6	11.38	2.79	nil	73.4			nil
11	Naph.	15.6				73.4	0.53	nil	nil

In this relationship the over-all mass-transfer coefficient K represents the summation of two individual film resistances defined as follows:

$$\frac{1}{K} = \frac{1}{k^d} + \frac{H}{k_c} \qquad (7)$$

The individual film resistances may be further defined according to the laws of unsteady-state diffusion as follows:

$$k_c = 1.13\left(\frac{a}{t_c}\right)^{1/2} \qquad (8)$$

(2, 9-10)

$$k_d = -\frac{r}{3t_{cd}}\ln\left(\frac{6}{\pi^2}\sum_{1}^{\infty}\frac{1}{n^2}\right)e\left(\frac{-Dn^2\pi^2t}{r^2}\right) \qquad (9)$$

(9)

The effective time in the relationship for continuous phase resistance is essentially given by the time required for a particle to travel a distance equal to its diameter of $2r$.

$$t_c = \frac{2r}{v}$$

and, t_c is the time between drop formation and reagglomeration. The diffusivities in the dispersed and continuous phases have been calculated by the method of Arnold *(2, 21, 23)* for both the MEK-water-naphtha system and furfural lubricating oil distillate system. These are given below in Table 5 together with values of H, the concentration ratio.

The stage concept of fractionating column performance as embodied in the Murphree efficiency analysis does not visualize appreciable effect on stage efficiency or stage height by the ratio of the dispersed to continuous phase flow. That this concept is substantially true, is indicated by the success of Drickamer and Bradford *(7)*, and H. E. O'Connell *(19)* in their generalized correlation of fractionating column performance without inclusion of this variable. Data of Moulton and Walkey *(16)* studying liquid-liquid extraction of the MEK-water-naphtha system also substantiate this. They found stage height to be largely a function of plate contact area over a wide range of V_d/V_c. No significant trend was apparent, plate efficiencies being roughly equal at the extremes of V_d/V_c.

In the MEK-water-naphtha system diffusivities of the water and naphtha phases are essentially equal. Also, physical characteristics of the phases are such that drop velocity would be approximately the same for either water or naphtha as the dispersed phase. This leads to similar k_d and k_c values with either water or naphtha dispersed. The principal variable affecting stage height is the parameter H, the effect of which may be analytically developed as follows:

If Equation (6) is rewritten in terms of the individual film resistances, it takes the following form:

$$\left(\frac{1}{k_{d_1}} + \frac{H_1}{k_{c_1}}\right)\frac{r_1}{t_1} = \left(\frac{1}{k_{d_2}} + \frac{H_2}{k_{c_2}}\right)\frac{r_2}{t_2} \qquad (10)$$

The time of rise in the equivalent stage heights is related to the velocity of drop travel by the following relationship:

$$t_1 = \frac{h_1}{v_1}\,t_2 = \frac{h_2}{v_2} \qquad (11)$$

Since drop velocity and radius are equivalent for the case of simple reversal of phase in MEK-water extraction, Equation (10) may be written as follows:

$$\left(\frac{1}{k_d} + \frac{H_1}{k_c}\right)\frac{1}{h_1} = \left(\frac{1}{k_d} + \frac{H_2}{k_c}\right)\frac{1}{h_2} \qquad (12)$$

TABLE A

RUN DATA - LUBRICATING OIL EXTRACTION

Run No.	35	36	37	38	39	40	41	42	43	44	45
Raffinate Yield (Gravity), %	44.3	36.6	30.1	33.0	44.1	40.3	49.1	56.0	52.4	54.8	42.6
V1 - Raffinate	91.0	96.5	106.0	93.0	88.6	96.6	85.4	78.0	81.3	77.7	89.8
Feed	4	4	4	4	4	4	4	4	4	4	4
V10 - Raffinate	0.830	0.884	0.950	0.855	0.810	0.884	0.814	0.835	0.821	0.814	0.810
Extract	0.845	0.934	0.927	0.908	0.944	0.939	0.934	0.950	0.956	0.956	0.939
Feed	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884
°API Gr. at 60°F. Raffinate	28.2	29.2	31.4	29.3	28.2	29.2	27.5	25.7	26.4	25.7	28.0
Extract	8.3	10.0	10.9	10.9	8.4	9.0	7.0	6.2	6.9	6.7	9.0
Feed	16.9	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Sep. Univ. sec. Raffinate	74.9	71.6	68.6	70.2	74.3	72.0	73.4	82.2	79.8	81.7	75.6
at 210°F. Extract	481.5	361.5	314.3	345.6	480.5	438.7	523.4	779.2	685.6	639.6	453.8
Feed	180.3	180.3	180.3	180.3	180.3	180.3	180.3	180.3	180.3	180.3	180.3
Sep. Univ. sec. Raffinate	758.1	654.7	548.5	648.6	762.3	661.6	808.4	1056.1	935.2	1043.7	786.8
at 100°F. Feed	6660	6660	6660	6660	6660	6660	6660	6660	6660	6660	6660
Furfural/Feed Ratio	6.4	8.1	17.0	6.0	4.5	12.0	10.0	5.0	4.5	2.6	7.4
Reflux Ratio	2	2	5	°0*	°0*	5	5	2	°0*	0.3	0.3
Continuous Phase	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil
Feed, gal/hr./sq.ft.	20.4	27.8	10.2	11.3	11.3	13.6	13.6	13.6	13.6	20.4	28.3

TABLE 5

DIFFUSIVITIES AND CONCENTRATION RATIOS IN MEK- WATER- NAPHTHA SYSTEM AND FURFURAL LUBRICATING OIL SYSTEM

Diffusivities Methyl-Ethyl-Ketone

Column Location	Water Phase	Gasoline Phase
Top	1.15×10^{-5} sq.ft./sec.	1.36×10^{-5} sq.ft./sec.
Middle	1.08×10^{-5}	1.37×10^{-5}
Bottom	0.87×10^{-5}	1.47×10^{-5}

Diffusivities Lubricating Oil

Column Location	Furfural Phase	Oil Phase
Top	5.0×10^{-9} sq.ft./sec.	1.07×10^{-9} sq.ft./sec.
Middle	4.4×10^{-9}	$.90 \times 10^{-9}$
Bottom	3.8×10^{-9}	$.27 \times 10^{-9}$

Concentration Ratio MEK Between Naphtha and Water

Volume % MEK in Water Phase	Vol. % MEK in Naphtha Phase	Concentr. in Naph. Phase / Concentr. in Water Phase
1	0.985	0.985
5	5.30	1.06
10	14.20	1.42
15	33.00	2.20
20	65.0	3.25
25	85.25	3.42

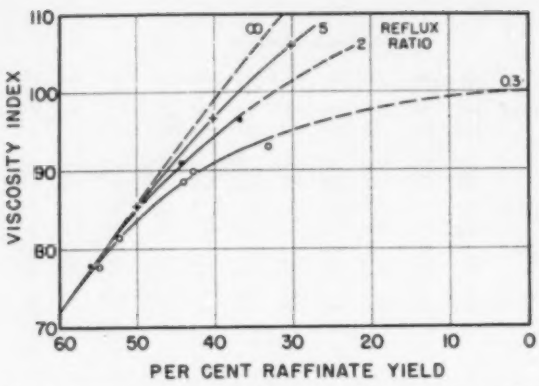


Fig. 5. Viscosity index of refined oil vs. yield in solvent refining pilot plant.

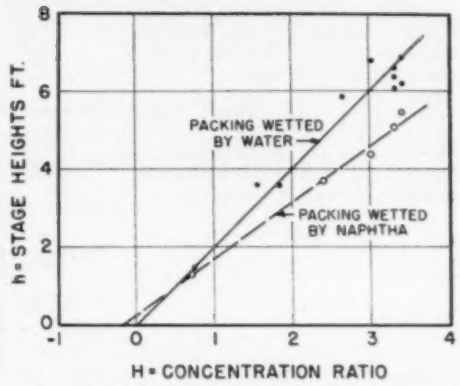


Fig. 6. Stage height vs. concentration ratio in pilot plant column water-mek-naphtha system.

The general expression of this relationship is given as follows:

$$h = C\left(\frac{1}{k_d} + \frac{H}{k_c}\right) \qquad (13)$$

When stage height is plotted against H for this system, the ratio k_c to k_d is given by intersection of a straight line with the X axis:

$$\text{Intercept } X_{axis} = \frac{k_c}{k_d} \qquad (14)$$

A plot of the experimental data obtained in the MEK-water-naphtha system is given in Figure 6. Intercept of the best straight lines to the experimental data at the X axis is essentially zero, showing that the value k_d is large compared with that of k_c. This is in agreement with the estimated value of k_d according to Equation (9) and is supported by the work of Sherwood, Evans, and Longcor (*24*) who found that the individual film coefficients for drops is 25- to 30-fold that shown by Equation (9) due to the internal convection effects. Johnson and Bliss (*14*) in their studies on a variety of systems found Kga overall to be a function of H. The successful correlation of experimental data of the *MEK*-water-naphtha system, in which there is approximately a five-fold variation in stage height and concentration ratio, constitutes an impressive demonstration of the validity of the theoretical development above.

The continuous phase is controlling in the furfural lubricating oil distillate system. Diffusivities given in Table 5 show the continuous phase to have values on the order of one tenth that of the dispersed phase. Comparative extraction column performance between the MEK-water-naphtha extraction system and the furfural lubricating oil distillate system reduced essentially to the relationship of the resistance of the continuous phase. The relationship of Equation (6) may be rewritten for this case as follows:

$$\frac{k_{c_1} t_1}{H_1 r_1} = \frac{k_{c_2} t_2}{H_2 r_2} \qquad (15)$$

Since drop diameter of the packed column is largely a constant function of packing characteristics, Equation (6) reduces still further to:

$$\frac{k_{c_1}}{H_1} t_1 = \frac{k_{c_2}}{H_2} t_2 \qquad (16)$$

Substituting the relationships of Equations (8) and (11), Equation (16) reduces to:

$$\frac{h_2}{h_1} = \left(\frac{a_1}{a_2}\right)^{1/6} \left(\frac{v_2}{v_1}\right)^{1/6} \left(\frac{H_2}{H_1}\right) \qquad (17)$$

Data of O'Brien and Gosline (*19*) have shown motion of bubbles over one tenth of an inch in diameter and larger to be in the turbulent region and essentially independent of viscosity of the continuous phase. Drop velocity is essentially a function of specific-gravity difference as given by Newton's law

$$v = C\sqrt{2gr\left(\frac{\rho_d - \rho_c}{\rho_c}\right)}$$

Substitution of this relationship reduces the expression for relative stage heights where continuous phase is controlling still further to the form as follows:

$$\frac{h_2}{h_1} = \left[\frac{a_1}{a_2}\right]^{1/2} \left[\left(\frac{\rho_d - \rho_c}{\rho_c}\right)_2 \left(\frac{\rho_c}{\rho_d - \rho_c}\right)_1\right]^{1/4} \left[\frac{H_2}{H_1}\right] \qquad (18)$$

Since diffusivity is a direct function of viscosity, this relationship for stage height is entirely analogous to that which O'Connell (*19*) successfully applied to the general correlation of tray efficiencies in fractionating columns. O'Connell did not require the specific-gravity correction term since this variable is nearly constant in distillation.

In the lubricating oil operations H_2 varied from 0.23 to 0.38 and total stages in the column varied from 16 to 10. These values are on the same order as those obtained by Rushton (*22*) in a similar column employing the nitrobenzene lubricating oil system.

It must be pointed out that the estimate of stage numbers in the furfural SAE 40 lubricating oil distillate system according to Equation (18) is approximate. However, analysis of the process variables by overlap concept is relatively insensitive to the minor variations in stage number which may be involved.

The overlap coefficient chart as developed by Meyer (*15*) and extended for extraction operations is shown in Figure 7. From a physical standpoint, the overlap coefficient originally represented the volume in milliliters of material in 200 ml. of distillate boiling above the cut-point temperature of the distillation, or the volume boiling below the cut-point temperature in the residue.

As now applied in both distillation and extraction, this simple definition is no longer true and it is essentially a numerical criterion representing the effectiveness of the separation process in either distillation or extraction. The basic assumption is that the feed consists of an infinite number of components distributed uniformly between the two extremes of physical characteristics determining the separation. In this case the determining physical characteristic is solubility in the solvent.

It is readily apparent in Figure 7 that high stage numbers require high reflux ratios to be fully effective and conversely low stage numbers can only effectively

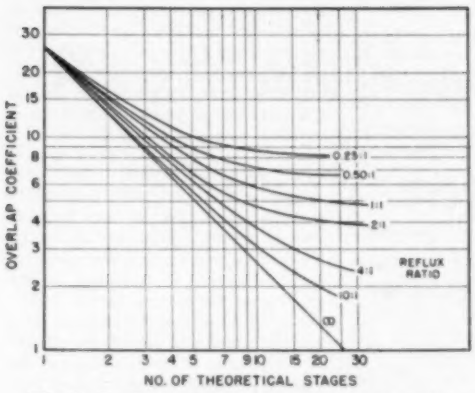


Fig. 7. Overlap coefficient for continuous extraction.

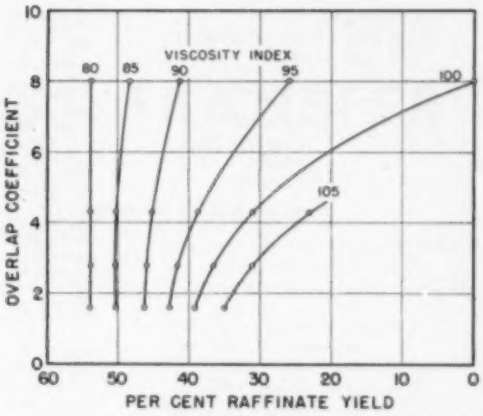


Fig. 8. Overlap coefficient vs. yield at constant viscosity index of refined oils.

utilize low reflux ratios. The correlation is a quantitative expression of the effects of stage number and reflux in extraction.

Application of Correlation to Commercial Design

Generalized Correlation of Data on Furfural Extraction of SAE 40 Dewaxed Lubricating Oil Distillate. Figure 8 was developed from the curves of Figures 5 and 7 by first determining the number of theoretical stages at each reflux ratio. The overlap coefficient for each reflux ratio was then obtained from Figure 7. The constant viscosity index curves shown in Figure 8 were then developed by obtaining the raffinate yield from Figure 5 and plotting overlap coefficient vs. raffinate yield. This plots the overlap coefficient necessary for the attainment of a specified yield of specified quality raffinate. If a 40% yield of 95 V.I. raffinate is desired, there must be an overlap coefficient of about 3.8. From Figure 7 it is apparent that the minimum reflux ratio is on the order of 2:1. The minimum plates would be 5.8 at total reflux. The separation could also be obtained at a 3:1 reflux ratio with 13 theoretical plates.

As an example of the use of these charts, consider a unit to handle 1000 bbl./day of dewaxed SAE 40 distillate producing 420 bbl./day of 90 viscosity index raffinate. There is an extraction column available with five theoretical plates. What reflux ratio and solvent circulation are required? From Figure 8 an overlap coefficient of 7.6 is necessary to obtain 42% of 90 V.I. raffinate. From Figure 7 it is seen that with five plates a reflux ratio of 0.75:1 is necessary to obtain a 7.6 overlap coefficient.

The extract volume is then (1.75) (580) or 1015 bbl./day, of which 580 bbl./day are production and 435 bbl./day are reflux. To remove this extract as a 20% solution, one needs 4060 bbl./day of solvent. The 420 bbl./day of raffinate would leave containing 10% solvent or 47 bbl./day. The total solvent circulation is then 4060 + 47 or 4107 bbl./day.

Effect of Variation in Stage Number on Multicomponent Extraction. Consider the effect of adding another five-stage extraction column in series with the first. This would give a more efficient system, which could be utilized in several ways. The reflux ratio could be reduced with a saving in furfural circulation, or by keeping the same reflux ratio, the yield could be enhanced, or the yield could be retained and a better raffinate produced.

With ten stages and a required overlap coefficient of 7.6, Figure 7 shows that a reflux ratio of 0.40:1 is needed. The total solvent requirement is then (4) (1.40) (580) + (0.11) (420) or 3297 bbl./day, representing a saving of 810 bbl./day or 19.7% less than the 4107 bbl./day needed with five stages.

If the 0.75:1 reflux ratio is retained, Figure 7 gives an overlap coefficient of 6.4 for ten stages. This would give us a 43.5% yield of 90 V.I. raffinate from Figure 8, representing an increase of 3.6% over the 42% yield at 7.6 overlap coefficient. In this case some solvent circulation is also saved since less extract is made. The solvent circulation would be (4) (1.75) (565) + (0.11) (435) = 4003 bbl./day, a saving of 104 bbl./day or 2.5% over the 4107 bbl./day needed with five stages.

Using the overlap coefficient of 6.4 obtained with ten stages and .75:1 reflux ratio but keeping the 42% yield, Figure 8 shows a small quality improvement to 91 viscosity index.

Use of General Correlation for Modification to Existing Solvent Extraction Equipment. The overlap coefficient plot (Fig. 7) is not limited to the use of any specified solvent or feed oil. It would be equally valid on any extraction operation conducted continuously.

This chart is of potential value when modifications in existing equipment are considered from the standpoint of increasing the number of plates in order to reduce reflux ratio and hence solvent circulation.

As an example of this, consider a three-stage extraction column producing a 30% raffinate at one to one reflux ratio. This column has an overlap coefficient of 9.2. If the column is increased to five plates, the reflux ratio can be reduced to 0.3:1, keeping the same overlap coefficient. Assuming 20% extract solubility in solvent and 20% solvent solubility in raffinate, the three-plate column would need (2) (700) (4) + (0.25) (300) = 5675 bbl./day of solvent to produce 300 bbl./day of raffinate. The five-stage column, on the other hand, would only need (1.3) (700) (4) + (0.25) (300) = 3715 bbl./day of solvent, a saving of 1960 bbl./day or 34.5%.

Acknowledgment

The authors wish to express their appreciation to the Union Oil Co. for permission to publish this study of process variables in multicomponent extraction.

Notation

A = interfacial area corresponding to V volume, sq.ft.

c = concentration of a constituent in liquid phase, lb. mole/cu.ft.

c^* = concentration of a constituent in a liquid bubble equivalent to equilibrium with main body of liquid

C = constant
E_m = local Murphree efficiency
h = stage height, ft.
$H = \frac{c_i}{c_i'}$ = concentration ratio for a constituent, dispersed phase/continuous phase for multicomponent extraction $\frac{c_d}{c_c}\left(\frac{V}{O}\right)$
H.E.T.S. = height of one equivalent transfer stage, ft.
H.T.U. = height of one transfer unit, ft.
k = liquid-transfer coefficient, lb. mole/(sq. ft.)(sec.)(lb. mole/cu.ft.)
K = over-all transfer coefficient lb. mole/(sq. ft.)(sec.)(lb. mole/cu.ft.)
ln = natural logarithm of
O = oil rate up the column, cu.ft./sec.
r = bubble radius equivalent sphere, ft.
t = time, sec.
t_c = average time of contact for liquid surface surrounding a bubble, sec.
v = velocity of rise of a bubble, ft./sec.
V = gas rate up or oil rate down the column, cu.ft./sec. or volume of liquid, cu.ft.
V.G.C. = viscosity gravity constant
V.I. = viscosity index

GREEK LETTERS:

μ = viscosity, lb./(sec.)(ft.) $= 6.72 \times 10^{-4} \times$ centipoises
ρ = density, lb./cu.ft.
α = diffusion coefficient of constituent in liquid, sq.ft./sec.
$\pi = 3.1416$

SUBSCRIPTS:

c = continuous phase
d = dispersed phase
i = dispersed film at interface
i' = continuous film at interface
f = final state
o = initial uniform condition of bubble
1,2,etc. = conditions or state 1, 2, etc.

Literature Cited

1. Appel, F. J., and Elgin, J. C., *Ind. Eng. Chem.*, **29**, 451 (1937).
2. Arnold, J. H., *J. Am. Chem. Soc.*, **52**, 3937 (1930).
3. Berg, Clyde, and Parker, F. D., *Anal. Chem.*, **20**, 456 (1948).
4. Blanding, F. H., and Elgin, J. C., *Trans. Am. Inst. Chem. Engrs.*, **38**, 305 (1942).
5. Colburn, A. P., and Welsh, D. G., *Trans. Am. Inst. Chem. Engrs.*, **38**, 179 (1942).
6. Comings, B. W., and Briggs, S. W., *Trans. Am. Inst. Chem. Engrs.*, **38**, 143 (1942).
7. Drickamer, H. G., and Bradford, J. R., *Trans. Am. Inst. Chem. Engrs.*, **39**, 319 (1943).
8. Fallah, R., Hunter, T. G., and Nash, A. W., *J. Soc. Chem. Ind.* (London), **54**, 49T (1935).
9. Geddes, R. L., *Trans. Am. Inst. Chem. Engrs.*, **42**, 79 (1946).
10. Higbie, R., *Trans. Am. Inst. Chem. Engrs.*, **31**, 365 (1934) (1935).
11. Hunter, T. G., and Nash, A. W., *J. Soc. Chem. Ind.*, **51**, 285T (1932).
12. Hunter, T. G., and Nash, A. W., World Petroleum Congress, Sectional Volume **F**, 340 (1933).
13. Hunter, T. G., and Nash, A. W., *Ind. Eng. Chem.*, **27**, 836 (1935).
14. Johnson, H. F., and Bliss, H., *Trans. Am. Inst. Chem. Engrs.*, **42**, 331 (1946).
15. Meyer, P., *J. Inst. Petroleum Technol.*, **19**, 819 (1933).
16. Moulton, R. W., and Walkey, J. E., *Trans. Am. Inst. Chem. Engrs.*, **40**, 695 (1944).
17. Murphree, E. V., *Ind. Eng. Chem.*, **17**, 747 (1936).
18. O'Brien, M. P., and Gosline, J. E., *Ind. Eng. Chem.*, **27**, 1436 (1935).
19. O'Connell, H. E., *Trans. Am. Inst. Chem. Engrs.*, **42**, 741 (1946).
20. Othmer, D. F., White, R. E., and Trueger, E., *Ind. Eng. Chem.*, **33**, 1240 (1941).
21. Powell, R. E., Roseveare, W. E., and Eyring, H., *Ind. Eng. Chem.*, **33**, 430 (1941).
22. Rushton, J. H., *Ind. Eng. Chem.*, **29**, 309 (1937).
23. Scheibel, E. G., and Othmer, D. B., *Trans. Am. Inst. Chem. Engrs.*, **40**, 611 (1944).
24. Sherwood, T. K., Evans, J. E., and Longcor, J. V. A., *Ind. Eng. Chem.*, **31**, 1145 (1939).
25. Sherwood, T. K., Evans, J. E., and Longcor, J. V. A., *Trans. Am. Inst. Chem. Engrs.*, **35**, 597 (1939).
26. Varteressian, K. A., and Fenske, M. R., *Ind. Eng. Chem.*, **28**, 1353 (1936).

Discussion

F. J. Lockhart (University of Southern California, Los Angeles, Calif.): Can you explain the overlap coefficient in more detail? I'm familiar with the article by Meyer and its application to distillation, but how does the Meyer definition change when applied to solvent extraction?

Clyde Berg: The Meyer overlap correlation is a means of correlating the results of the fractionation of a mixture of an infinite number of components and was set up originally for a naphtha mixture. Meyer fractionated a definite quantity of naphtha, e.g., 400 ml., into 50% overhead product and 50% bottoms product and called overlap the volume in milliliters of material boiling above the 50% point which contaminated his overhead product. The amount of overlap can be evaluated mathematically by calculating the binary separation for various components as volatility ratio varies from zero to infinity and integrating over the range for the amount of contaminating material which would be taken overhead in the process of a separation with a given number of trays and a given reflux ratio. The rather simple derivation is readily extended to mixtures which have not been fractionated at the 50% point, but at the 10, 15, or 25% points, in which cases the use is adjusted by definition of the meaning of the overlap factor. Lubricating oil is as near an approach to a material containing an infinite number of components as may occur, and the analogy to the above separation mechanism is direct. The definition of overlap as Mr. Meyer set it up is academic and only applicable to the original 400 ml. However, as a criterion it is applicable to the distillation of mixtures of quite different boiling ranges and is useful in extraction and other types of separation as well.

F. J. Lockhart: Do I understand that the overlap coefficient is some sort of a nebulous concept as to the effectiveness of separation? Now I agree that as the overlap coefficient decreases, we get a better separation. So far, we can't tie those two together very definitely. Is that correct?

Clyde Berg: The overlap coefficient can be precisely evaluated for a given case, but is applied in multicomponent mixtures as an index. The numerical value of the coefficient has no meaning to us any more. It's simply an indicator of what you're doing in a column which combines a given number of stages and a given reflux ratio.

F. J. Lockhart: Before you can actually make use of this concept, you must have pilot plant data or laboratory data so that you have a known number of theoretical contacts and reflux ratio in order to get the overlap coefficient. Is that right?

Clyde Berg: That is absolutely right. And the achievement of this particular correlation is the use of the overlap coefficient, not as an absolute value, but as a parameter for plotting results and thereby obtaining a more generalized interpretation.

F. J. Lockhart: I am glad to see the overlap coefficient so applied. It has been my belief that some modification of it could be used very effectively in distillation calculations, although I have seen no work done on it after Meyer made his publication.

(Presented at Los Angeles (Calif.) Meeting.)

HEAT AND MASS TRANSFER

FLUID SOLID SYSTEMS

BERNARD W. GAMSON

Great Lakes Carbon Corporation, Chicago, Illinois

Correlations are developed which permit the evaluation of heat- and mass-transfer factors and coefficients for fixed and fluidized beds. Most of the available data in the literature are consolidated onto a single curve when the transfer takes place between the fluid stream, either gas or liquid, and the particle. Generalized equations are also presented for the case of heat and mass transfer between the reactor surface or interchangers in the fluid stream for fluidized beds. The maximum deviation of the available experimental data with the correlations is about ±10% for particle to fluid transfer and ±20% for exchanger surface to fluid transfer.

SEVERAL different concepts have been employed in the development of expressions relating heat- and mass-transfer phenomena in the flow of fluids through conduits and granular solids in fixed beds. The two most useful concepts are those of the transfer coefficient and the j transfer factors. For heat transfer, the coefficient h is defined:

$$q = haV(\Delta t)_m \qquad (1)$$

The mass-transfer coefficient is defined as

$$w = kaV(\Delta 1)_m \qquad (2)$$

The j transfer factors were first developed by Colburn (*3*) for the gas film. McCune and Wilhelm (*10*) and Hobson and Thodos (*5*) extended the use of the j factor concept to the liquid film for mass transfer between liquids and granular solids. They showed that in fixed beds, j_d for liquids and gases were identical. For heat transfer, Colburn (*3*) developed

$$j_h = \frac{h}{c_p G}\left[\frac{c_p \mu}{k}\right]_f^{2/3} \qquad (3)$$

For mass transfer,

$$j_d = \frac{k\xi_p M_m}{G}\left[\frac{\mu}{\rho D_v}\right]_f^{2/3} \qquad (4)$$

Equations (3) and (4) are useful irrespective of the fluid phase, whether gaseous or liquid, under consideration.

Recent advances in the chemical engineering profession have been related to a great extent with operations involving, either separately or concurrently, mass and heat transfer in fluidized or fixed beds. Such data are of importance in processes involving both liquid and gaseous systems. It is especially desirable to have transfer data available for the fluid phase under consideration, independent of the other solids or fluids which may be participating in the overall transfer phenomena.

Quantitative methods for the prediction of these transfer data are indispensable to the satisfactory design of many chemical processes. They are useful in such diverse operations as the chemical reaction of fluids in the presence of a solid catalyst, the reaction between a granular solid and a fluid, the adsorption of fluids on solid particles, liquid-solid and liquid-liquid extraction phenomena, exchange processes, drying, sublimation and dissolution problems. Such data are of extreme significance in the design of industrial processes involving heat transfer between granular solids in fluidized systems and the walls of the vessel or interchangers inserted in the reaction system proper.

Accordingly, this study was initiated to develop generalized expressions which would permit the calculation of mass-transfer and heat-transfer coefficients for fluids participating in either fixed or fluidized systems, based solely upon the physical definition of the system and the properties of the participating fluids.

Heat and Mass Transfer Between Fluids and Solids

The published experimental data on heat and mass transfer between fluids and solids are as yet relatively meager when compared with the extensive publications on transfer phenomena in conduits. Generalized correlations of heat- and mass-transfer coefficients of the gas film for gases flowing through a fixed granular bed of solid spheres and cylinders were developed by Gamson, Thodos and Hougen (*4*) and Wilke and Hougen (*16*). Taecker and Hougen (*14*) reported correlations on commercial tower packings such as Raschig rings, partition rings and Berl saddles. Experimental data were obtained by measuring the rate of evaporation of water into a stream of air from wetted granules and packings during the constant drying-rate period (*4, 14, 16*). Hurt (*6*) and Resnick and White (*13*) presented mass-transfer data for the evaporation of naphthalene into a stream of flowing air. The naphthalene results were not in agreement with each other or with the data of Hougen and coworkers.

Gamson et al (*4*) correlated j_h and j_d against a modified Reynolds number $D_p G/\mu$. The effective particle diameter, D_p, was defined as the diameter of a sphere having the same surface area as the particle. Thus,

$$D_p = \sqrt{\frac{A_p}{\pi}}$$

where A_p is the area of the particle. Wilke and Hougen correlated their data using the parameters of (*4*). Taecker and Hougen (*14*) suggested using a modified Reynolds number defined as

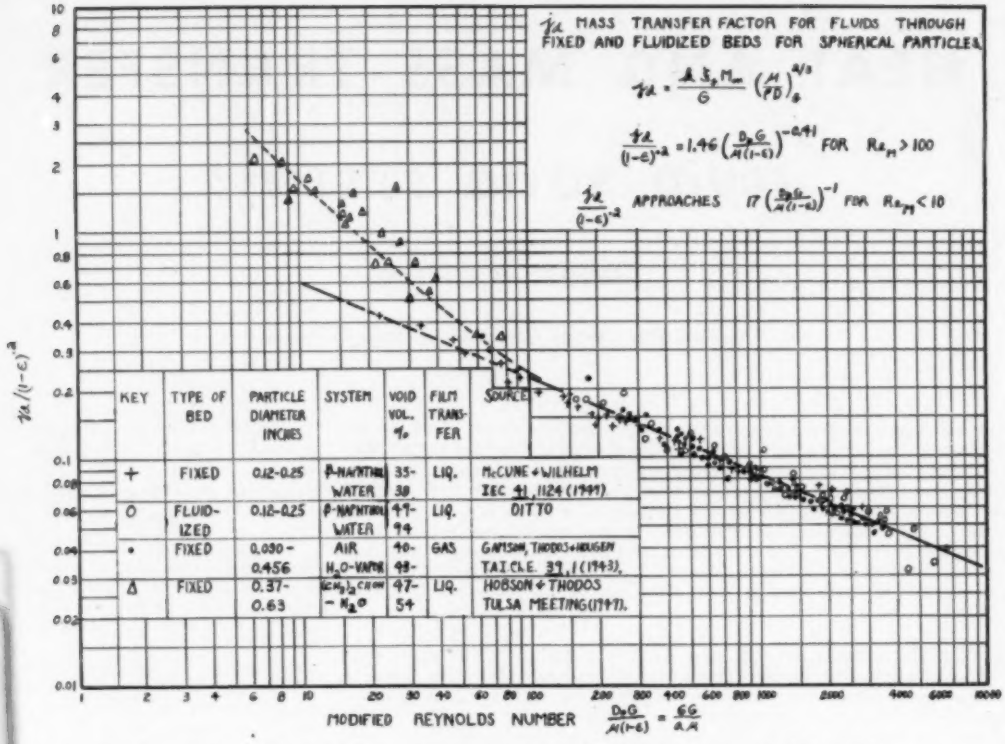

j_d MASS TRANSFER FACTOR FOR FLUIDS THROUGH FIXED AND FLUIDIZED BEDS FOR SPHERICAL PARTICLES
$j_d = \frac{A}{G}\frac{S_p M_m}{}\left(\frac{\mu}{PD}\right)_g^{2/3}$
$\frac{j_d}{(1-\epsilon)^{2}} = 1.46\left(\frac{D_p G}{\mu(1-\epsilon)}\right)^{-0.41}$ FOR $Re_M > 100$
$\frac{j_d}{(1-\epsilon)^{2}}$ APPROACHES $17\left(\frac{D_p G}{\mu(1-\epsilon)}\right)^{-1}$ FOR $Re_M < 10$
KEY | TYPE OF BED | PARTICLE DIAMETER INCHES | SYSTEM | VOID VOL. % | FILM TRANSFER | SOURCE
+ | FIXED | 0.12-0.25 | β-NAPHTHOL WATER | 35-38 | LIQ. | McCUNE & WILHELM IEC 41, 1124 (1949)
O | FLUIDIZED | 0.12-0.25 | β-NAPHTHOL WATER | 91-94 | LIQ. | DITTO
• | FIXED | 0.030-0.456 | AIR H_2O-VAPOR | 40-48 | GAS | GAMSON, THODOS & HOUGEN TAIChE 39, 1 (1943)
Δ | FIXED | 0.37-0.63 | BENZOIC ACID - N_2O | 47-54 | LIQ. | HOBSON & THODOS TULSA MEETING (1949)
$j_d/(1-\epsilon)^2$
MODIFIED REYNOLDS NUMBER $\frac{D_p G}{\mu(1-\epsilon)} = \frac{6G}{a\mu}$

Fig. 1. J_d **mass-transfer factor for fluids through fixed and fluidized beds for spherical particles.**

$G\sqrt{A_p}/\mu$ instead of D_pG/μ. These two moduli are related by

$$\frac{D_pG}{\mu} = 0.567\,\frac{G\sqrt{A_p}}{\mu} \qquad (5)$$

Thecker and Hougen reported separate curves for the j factors versus modified Reynolds number for both heat and mass for Berl saddles, spheres and/or cylinders, and Raschig rings and/or partition rings.

Hobson and Thodos (*5*) obtained mass-transfer data for the liquid systems methyl ethyl ketone-water and isobutyl alcohol-water with spherical solids in fixed beds. The transferable liquid was adsorbed on the particle and subsequently removed by the water stream. Their experimental results were extrapolated to zero time and a totally wetted surface in order to calculate steady-state transfer coefficients. These data fitted the same generalized correlation developed by Gamson et al (*4*) which was based on the gas film. This is somewhat striking in view of the 2000 to 1 variation in the Schmidt group. McCune and Wilhelm (*10*) also report data on mass transfer between granular solids and flowing liquids. They studied the dissolution of β-naphthol in water under steady-state conditions. It is noteworthy that their results when correlated as j factor against modified Reynolds number yielded an identical correlation with the gas-phase data of (*4*) and (*16*) and the liquid phase data of (*5*). McCune and Wilhelm also reported data for the system β-naphthol water in fluidized beds. The fluidized bed data were correlated as j factors vs. modified Reynolds number. No unique correlation existed and separate families of curves were required for spheres and mesh-size particles as a function of particle size. McCune and Wilhelm developed unique curves for spheres and mesh-size particles, respectively, when correlating j factors as a function of Re_M/f' or $(Re_M)^2/K_{\Delta\varphi}$. In these moduli the following definitions are employed:

$$f' = \frac{g_c D_p \Delta P}{2L_a\mu_a{}^2\rho} \qquad (6)$$

$$L_a = L(1-\epsilon) \qquad (7)$$

$$K_{\Delta\varphi} = \frac{D_p{}^3\rho g_c}{2\mu^2}\left(\frac{\Delta P}{L_a}\right) \qquad (8)$$

The correlating procedure of (*10*) yields no continuity between fixed and fluidized beds and is unwieldly for estimating mass-transfer phenomena in fluidized beds.

Data. A new generalized correlation for the evaluation of heat and mass transfer between fluids and particles is presented below. It is predicated primarily upon the concept that a continuity exists between fixed and fluidized beds. This continuity may be expressed by means of a modified Reynolds number which is defined in terms of an area per unit volume factor rather than an equivalent particle diameter. Although the correlation is based upon fluidization data which are of the particulate variety, it appears likely that the same correlation may be employed for aggregative fluidization when the area term is appropriately modified.

Gamson et al (*4*), Hobson and Thodos (*5*) and McCune and Wilhelm (*10*) report mass-transfer data for spherical particles. When these data are plotted as j_d factors versus a modified Reynolds number characterized by $6G/a\mu$, a series of curves results, with the void volume of the system as the parameter. All the above-reported

mass-transfer data for spherical particles may be consolidated into a single generalized correlation by plotting

$$\left(\frac{j_d}{(1-\epsilon)^{0.2}}\right) \text{ versus } \left(\frac{6G}{a\mu}\right)$$

The modified Reynolds number employed as $(6G/a\mu)$ is obtained by transforming the particle diameter for a sphere to specific surface by means of the following expression:

$$D_p = 6\frac{(1-\epsilon)}{a} \qquad (9)$$

Thus,

$$\frac{D_pG}{\mu(1-\epsilon)} = \frac{6G}{a\mu} \qquad (10)$$

Figure 1 is a plot of the j_d mass-transfer factor divided by the voidage parameter $(1-\epsilon)^{0.2}$ for the available data on spheres. The variables covered are fixed and particulate fluidized beds, particle diameters of 0.09 to 0.63 in., void volumes of 35-94%, gas and liquid films, Schmidt numbers of 1-2000 and modified Reynolds numbers of 7 to 7000. The degree of agreement of such diverse data is excellent. Although the data fall on a smooth continuous curve, three distinct regions are evident. For modified Reynolds numbers

$$\frac{6G}{a\mu} > 100$$

the data can be represented by the following equation for spheres:

$$j_d = 1.46\left(\frac{6G}{a\mu}\right)^{-0.41}(1-\epsilon)^{0.2}$$

for

$$\frac{6G}{a\mu} > 100 \qquad (11)$$

Between modified Reynolds numbers of 10 and 100, a transition region apparently exists which is best characterized by Table 1. For Re_M less than about 10, the

$$\frac{j_d}{(1-\epsilon)^{0.2}}$$

factor for spheres appears to approach

$$j_d = 17\left(\frac{6G}{a\mu}\right)^{-1}(1-\epsilon)^{0.2} \text{ for } \frac{6G}{a\mu} < 10 \qquad (12)$$

Data of Hobson and Thodos (*5*) on methyl ethyl ketone-water and that of McCune and Wilhelm (*10*) on β-naphthol-water are not in as good agreement as could be desired in the transition zone. It is likely that the flow pattern may be somewhat indefinite in the transition zone and highly dependent upon the specific nature of the system in a manner analogous to the flow of fluids in conduits.

Gamson et al (*4*) developed the relation between the j heat- and mass-transfer factors as

$$\frac{j_h}{j_d} = 1.076 \qquad (13)$$

In view of Equations (11), (12), and (13), Equations (14) and (15) define the j heat-transfer factor for spheres.

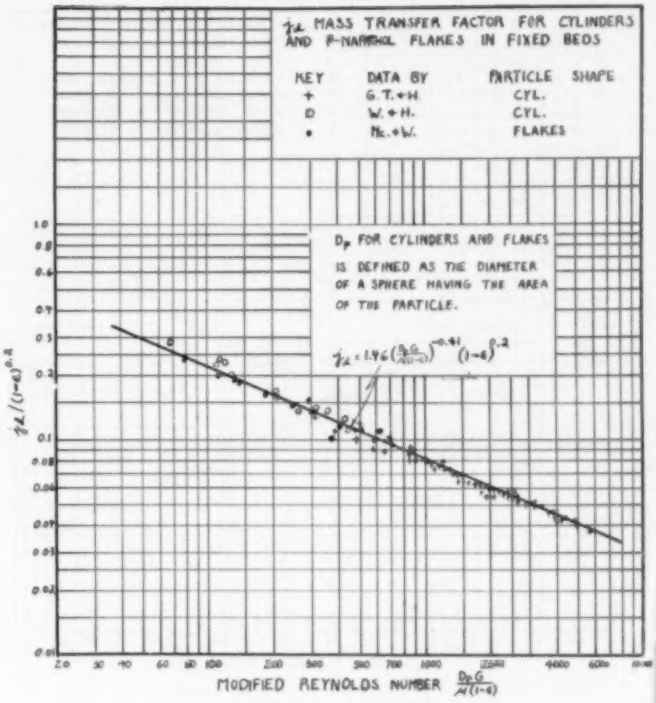

j_d MASS TRANSFER FACTOR FOR CYLINDERS AND β-NAPHTHOL FLAKES IN FIXED BEDS
KEY
DATA BY
PARTICLE SHAPE
+ G.T.+H. CYL.
□ W.+H. CYL.
• M.+W. FLAKES
D_p FOR CYLINDERS AND FLAKES IS DEFINED AS THE DIAMETER OF A SPHERE HAVING THE AREA OF THE PARTICLE.
$j_d = 1.96\left(\frac{D_pG}{a\mu(1-\epsilon)}\right)^{-0.41}(1-\epsilon)^{0.2}$
$j_d/(1-\epsilon)^{0.2}$
MODIFIED REYNOLDS NUMBER $\frac{D_pG}{a\mu(1-\epsilon)}$

Fig. 2. Mass transfer in fixed beds vs. $\frac{D_pG}{(1-\epsilon)\mu}$

$$j_h = 1.57\left(\frac{6G}{a\mu}\right)^{-0.41}(1-\epsilon)^{0.2}$$

for

$$Re_M > 100 \qquad (14)$$

$$j_h = 18.3\left(\frac{6G}{a\mu}\right)^{-1}(1-\epsilon)^{0.2}$$

for

$$Re_M < 10 \qquad (15)$$

It is worth while noting the similarity between the present correlation and that developed by Carman (*2*), Blake (*1*) and Kozeny (*7*) for momentum transfer in fluid flow in fixed beds and recently extended to fluidized systems by Morse (*12*). Carman found that the streamline region occurred at modified Reynolds numbers of $6G/a\mu$ less than 20 in which the friction factor was inversely proportional to the Reynolds number. A transition zone existed between Re_M of 20 and 100 and turbulent flow took place for Re_M greater than 100. These results also describe qualitatively the mass- and heat-transfer data. However, it should be emphasized that no quantitative generalization exists between j_h and j_d and the friction factor for flow of fluids in granular beds equivalent to that for fluid flow in conduits.

TABLE 1.—VALUES OF j_d AND j_h TRANSFER FACTORS IN RANGE OF

$$10 \leqslant Re_M \leqslant 100$$

$\frac{j_d}{(1-\epsilon)^{0.2}}$	$\frac{j_h}{(1-\epsilon)^{0.2}}$	Re_M
1.7	1.89	10
0.89	0.96	20
0.48	0.52	40
0.35	0.375	60
0.24	0.26	100

When the data of the various investigators for shapes other than spherical are correlated in the manner just described, separate curves are obtained for each shape which are essentially parallel to that for spheres but displaced below the latter. Observers (*4*), (*10*) and (*16*) were able to correlate cylinders and flakes on the same curve as for spheres by defining the particle diameter as that of a sphere with an area equal to that of the particle. A universal relationship for all commercial shapes did not exist. Figure 2 illustrates the agreement obtained when the available data on cylinders and flakes of observers (*4*), (*10*) and (*16*) are plotted as $j_d/(1-\epsilon)^{0.2}$ versus $D_pG/(1-\epsilon)\mu$ where the particle diameter is defined as above. The correlation is satisfactory. However, it fails in two important respects. First, the modified Reynolds number employed bears no relationship to $6G/a\mu$ and second, it does not yield a universal relationship for all shapes. In addition, the transfer factors for various commercial shapes fall both above and below the curve for spheres.

In order to correlate the existing data for miscellaneous shapes with that of spheres, it is necessary to introduce the

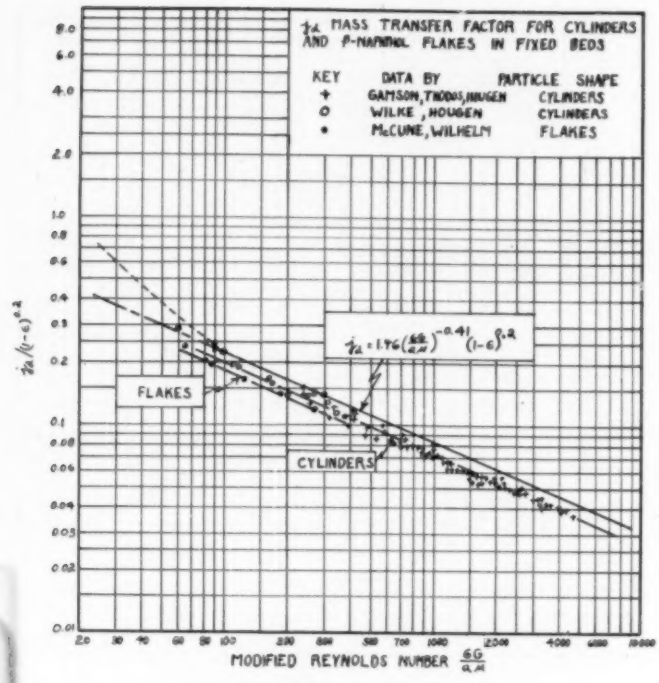


Fig. 3. Mass transfer in fixed beds vs. $\frac{6G}{a\mu}$

concept of a shape factor when the data are plotted against $6G/a\mu$. This shape factor is employed in order to compensate for that portion of the particle area which is not available for heat or mass transfer. In fixed beds, such unavailability of surface may be due to two primary effects. First, particle-to-particle contact which for shapes other than spherical cannot be point contacts and hence remove the contact area from being available for transfer phenomena. This phenomenon is observed in all particles other than spheres. The second factor is due to short-circuiting of available area by the fluid stream. This results with particles such as Raschig and partition rings where potential transfer area is relatively unavailable to the fluid steam and comparatively stagnant fluid exists in pockets.

In the case of fluidized beds, an apparent decrease in the total available particle area can occur in both particulate and aggregative fluidization. For particulate fluidization, particles other than spherical may show a surface effectiveness of less than unity because of particle orientation. This results in a nonuniform localized velocity pattern for the entire surface and is in contrast to that encountered with spheres. This effect may be more or less pronounced for a given type of particle as the modified Reynolds number changes. Where aggregative fluidization occurs the decrease in total available area arises because of cluster formation. Under these circumstances, two or more particles form an aggregate or clump which travels as an effective entity in the fluidized bed. The fluid flow is primarily around rather than through the cluster. The available surface area for transfer phenomena is then essentially controlled by the superficial diameter and area of the cluster. However, the porosity of the agglomerate will affect the available area because of permitting some gas passage through the cluster.

In view of the above discussion, a shape factor (ϕ_{ss}) is therefore defined as that factor which when employed in both the basic rate equation and the modified Reynolds number results in j factors for heat and mass transfer which fall on the universal correlation for spheres. Equations (1) and (2) become

$$q = h a \phi_{ss} V (\Delta t)_m \qquad (16)$$

$$w = k a \phi_{ss} V (\Delta 1)_m \qquad (17)$$

The modified Reynolds number is defined as

$$Re_M = \frac{6G}{a\phi_{ss}\mu} \qquad (18)$$

TABLE 2.—VOID VOLUMES OF RINGS AND BERL SADDLES (*14*)

Packing	Nominal Size—In.	Void Volume
Raschig rings	½	0.632
	1	0.71
	2	0.716
Partition rings		
Random	2	0.64
Staggered	2	0.53
Berl saddles	½	0.58
	½	0.60

The j and h transfer factors are then based upon coefficients calculated from Equations (16) and (17). This shape factor should not be confused with that of Carman's, ϕ_s, defined by

$$a = \frac{6(1-\epsilon)}{\phi_s D_p} \qquad (19)$$

Essentially, Equation (19) is a relationship between an effective particle diameter and a shape factor based upon the true particle area. It need bear no relationship to the effectiveness of the true particle area for transfer purposes.

The shape factor, ϕ_{ss}, is unity for a sphere and less than unity for all other shapes except, perhaps, in highly expanded fluidized beds at high Reynolds numbers.

Figure 3 graphically presents the data for cylinders and flakes. The Celite cylinders used by Gamson, Thodos and Hougen and Wilke and Hougen varied in nominal size from ⅛ in. to ¾ in. and in ratio of height to diameter of 0.89 to 1.25. The void volume varied from 35% to 41% and the bulk density of the dry particles was about 33-38 lb./cu.ft. the flaked 2-naphthol consisted of 8-10 and 14-18 mesh particles. Separate lines are obtained for cylinders and flakes without the introduction of a shape factor. Figure 4 is a consolidation of the available data on nonspherical particles in fixed beds covering cylinders, flakes, partition rings and Raschig rings, incorporating a shape factor. The void volumes employed for the rings are given in Table 2. The correlation is satisfactory. The correlating equations then become as follows:

For mass transfer:

$$j_d = 1.46\left(\frac{6G}{a\phi_{ss}\mu}\right)^{-0.41}(1-\epsilon)^{0.2} \quad Re_M > 100 \qquad (20)$$

$$j_d = 17\left(\frac{6G}{a\phi_{ss}\mu}\right)^{-1}(1-\epsilon)^{0.2} \quad Re_M < 10 \qquad (21)$$

For heat transfer:

$$j_h = 1.57\left(\frac{6G}{a\phi_{ss}\mu}\right)^{-0.41}(1-\epsilon)^{0.2} \quad Re_M > 100 \qquad (22)$$

$$j_h = 18.3\left(\frac{6G}{a\phi_{ss}\mu}\right)^{-1}(1-\epsilon)^{0.2} \quad Re_M < 10 \qquad (23)$$

For the data reported by (*4*), (*5*), (*14*) and (*16*), the general equations are slightly less accurate than the specific ones made by the various investigators for particular systems reported.

It should be emphasized that heat- and mass-transfer coefficients and corresponding j factors for the generalized Equations (20)-(23) are based upon Equations (16) and (17). If the transfer coefficients and transfer factors were based upon Equations (1) and (2), it would be necessary to multiply the right-hand side in Equations (20)-(23) by the shape factor ϕ_{ss}.

The available mass-transfer data for nonspherical particles in fluidized systems are

those of McCune and Wilhelm (*10*) for 2-naphthol flakes in water. These data are shown in Figure 5 with no correction for the shape factor. It is evident that the effective shape factor varies considerably depending upon the modified Reynolds number. The bulk of the data below Re_M of 100 for spherical particles of 2-naphthol were on a locus corresponding to an extension of Equation (*20*). On this basis, shape factors varying from 0.8 to unity are obtained. If the transition region is defined by the locus of points obtained from the data of Hobson and Thodos (*5*), the shape factor varies from about 0.6 to unity.

Figure 6 is a plot of the j heat-transfer factor for the Taecker and Hougen data on Berl saddles. These data do not quite fall on a parallel curve with the correlation of Figure 1. This is not surprising in view of the abnormal flow of fluid around Berl saddles. The shape factor varies from about 0.90 at Reynolds numbers above 1000 to around 0.75 at 100. The data can be correlated within the accuracy of the experimental data by Equation (*24*). This equation should not be extrapolated outside the values of modified Reynolds numbers over which actual data exist. Furthermore, this equation is based upon the evaluation of transfer coefficients and j factors by Equations (*1*) and (*2*). In the general case, however, an average value for the shape factor for Berl saddles of about 0.8 appears to place all the data above modified Reynolds numbers of 100 within the accuracy of Equation (*22*). If this average shape factor is used for the data below Re_M of 100, the points lie closer to an extension of Equation (*22*) than the locus obtained as the transition zone from the data of Hobson and Thodos. Further experimental work in this region is required to clarify the phenomena involved.

For Berl saddles $20 \leq Re_M \leq 1500$

$$j_h = 0.83 \left(\frac{6G}{a\mu}\right)^{-0.34} (1-\epsilon)^{0.8} \quad (24)$$

Table 3 summarizes the shape factors developed in this correlation to be used in conjunction with Equations (*20*)-(*23*). The present correlation has not considered the data of Hurt (*6*) and Resnick and White (*13*) because of the internal disagreement of their data on naphthalene vaporization. In addition, both contributors observed an apparent independent effect of particle size which was not obtained by authors (*4, 5, 10, 14, 16*).

It should be emphasized that for highly expanded beds, such as where the void volume is greater than about 97%, the correlations currently presented may not apply. This effect is observed because the modified Reynolds number may not be used any longer as the criterion of macroscopic flow. With high degrees of bed expansion, a segregation of particles takes place in the fluid stream corresponding somewhat to the velocity distribution of the fluid. Thus a particle concentration profile exists in a plane perpendicular to the direction of fluid flow with a maximum concentration near the wall and a minimum concentration at the center. Mass and heat transfer for single particles illustrates this phenomenon in the extreme. McCune and Wilhelm studied this matter with single spheres of 2-naphthol when the pellets were both at rest and suspended in motion. They observed that for suspended particles, the pellet nearly always assumed a position near the wall. Their data are shown in Figure 7. Satisfactory correlation is obtained by plotting the j_d factor against the fluid Reynolds number $\left(\frac{D_T G}{\mu}\right)$. This indicates that the controlling factor in the transfer for single particles is the flow characteristic of the fluid stream irrespective of particle size.

TABLE 3.—SHAPE FACTORS

Shape	ϕ_{as}
Spheres	1
Cylinders	0.91
Flakes	0.86
Raschig rings	0.79
Partition rings	0.67
Berl saddles	0.80

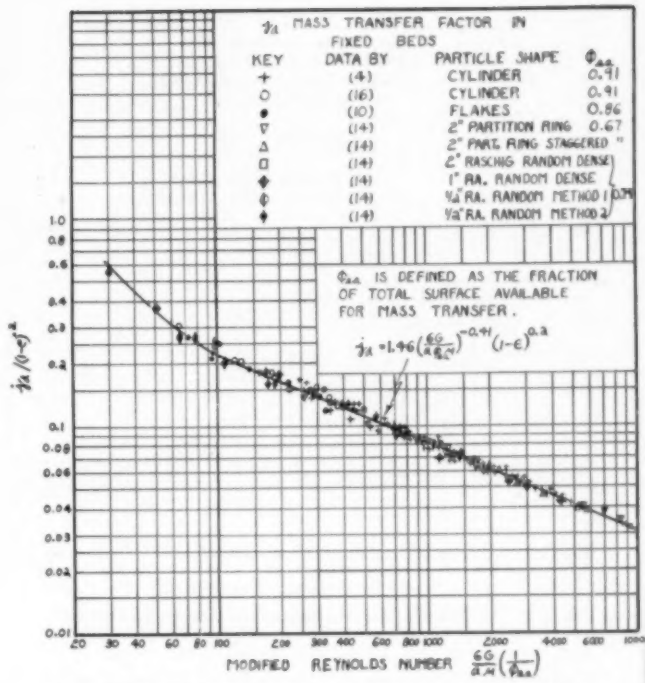

j_d MASS TRANSFER FACTOR IN FIXED BEDS
KEY DATA BY PARTICLE SHAPE ϕ_{as}
+ (4) CYLINDER 0.91
○ (16) CYLINDER 0.91
● (10) FLAKES 0.86
▽ (14) 2" PARTITION RING 0.67
△ (14) 2" PART. RING STAGGERED "
□ (14) 2" RASCHIG RANDOM DENSE
◆ (14) 1" RA. RANDOM DENSE
◇ (14) ½" RA. RANDOM METHOD 1 0.79
♦ (14) ½" RA. RANDOM METHOD 2
ϕ_{as} IS DEFINED AS THE FRACTION OF TOTAL SURFACE AVAILABLE FOR MASS TRANSFER.
$j_d = 1.46\left(\frac{6G}{a\mu_M}\right)^{-0.41}(1-\epsilon)^{0.2}$
$j_d/(1-\epsilon)^{0.8}$
MODIFIED REYNOLDS NUMBER $\frac{6G}{a\mu_M}\left(\frac{1}{\phi_{as}}\right)$

Fig. 4. Mass transfer in fixed beds including effect of a shape factor.

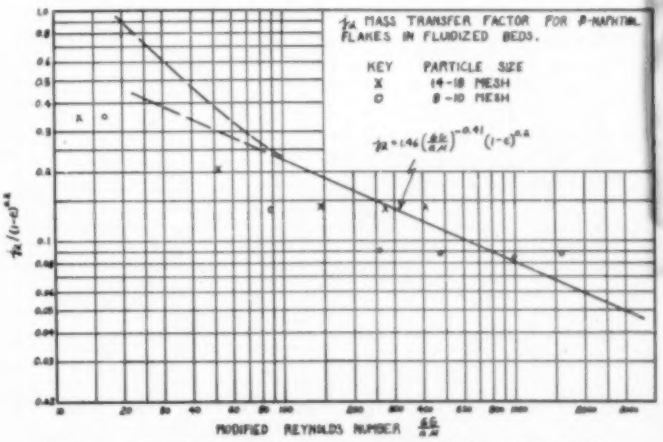


Fig. 5. J_d mass-transfer factor for β-naphthol flakes in fluidized beds.

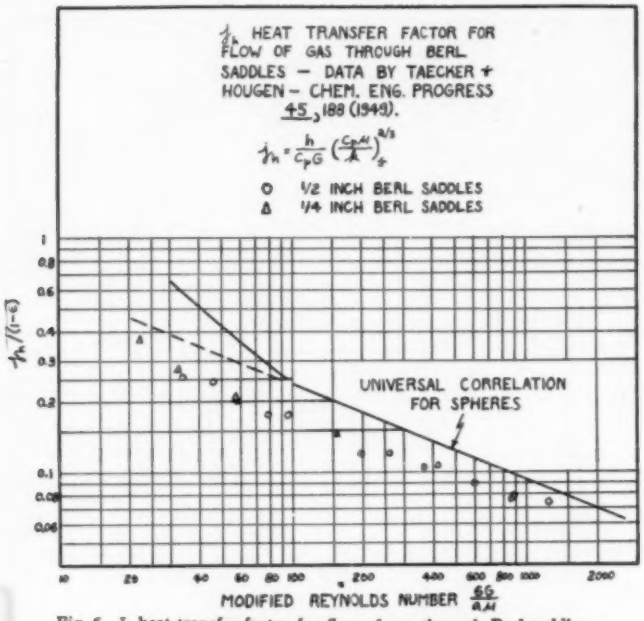

j_h HEAT TRANSFER FACTOR FOR FLOW OF GAS THROUGH BERL SADDLES — DATA BY TAECKER + HOUGEN — CHEM. ENG. PROGRESS 45, 188 (1949).
$j_h = \frac{h}{c_p G}\left(\frac{c_p \mu}{k}\right)^{2/3}_{\phi}$
O 1/2 INCH BERL SADDLES
Δ 1/4 INCH BERL SADDLES
UNIVERSAL CORRELATION FOR SPHERES
$j_h/(1-\epsilon)$
MODIFIED REYNOLDS NUMBER $\frac{DG}{\mu(1-\epsilon)}$

Fig. 6. J_h heat-transfer factor for flow of gas through Berl saddles.

This relation probably holds true only to some maximum ratio of particle to tube diameter.

Heat Transfer Between Fluidized Solids and Interchangers

Another aspect of the problem of being able to design *a priori* the most satisfactory fluidized reactor necessitates a knowledge of the rate of heat transfer between the fluid stream and any heat exchangers in the system. In the general case, such heat exchangers may be the walls of the reactor or surfaces inserted in the fluidized bed proper.

The mechanism of heat exchange between the fluid stream and the heat-transfer surfaces has as yet not been completely elucidated in the published literature. Mickley and Trilling (*11*) studied this subject experimentally and observed heat-transfer rates 3 to 70 times greater than could be obtained at the same gas mass velocity in the total absence of particles. They concluded that the increased rate of heat transfer resulted from the transport of heat by the solid particles from the hot to the cold regions in the fluid stream.

A mechanism for this type of heat transfer is proposed here which, it is believed, permits establishing the controlling variables and the nature of the relationship between them. For flow of fluids in conduits, the resistance to heat and mass transfer lies in the laminar layer, the buffer zone and the turbulent core. This results in a gas velocity and temperature profiles radially which are dependent upon the Reynolds number of the fluid stream. The presence of particles in the fluidized state substantially eliminates all temperature gradients in the stream's core because of transport of heat by the turbulent particles. In addition to the elimination of temperature gradients in the core, it is to be expected that the presence of the solids will reduce and minimize the extent of the buffer region and at the same time reduce the effective thickness of the laminar layer. The temperature traverse data of Mickley and Trilling corroborate these phenomena and indicate that the temperature gradient is localized in a thin layer near the exchanger wall. It is postulated that the primary method of heat transfer occurs by conduction across this film. Mickley and Trilling also suggest that some heat transfer occurs by convection due to the disruption of the film by the fluidized solids and that heat is transferred across the layer directly by the heat-carrying solids. The transfer of heat across the film is followed by transport of energy from the fluid to the particle and release of energy by the particle to the colder portions of the fluid stream.

Because of the decrease in the effective film thickness, the heat-transfer coefficient in the presence of solids is always greater than for fluid flow in the absence of particles.

The degree of distortion of the normal temperature distribution is based upon the particle size, particle shape, population of particles in the stream and the physical properties of the fluidizing medium. It is therefore suggested that the criterion of the disruption of the normal velocity and temperature profile for the flow of fluids in conduits due to the presence of fluidized solids be taken

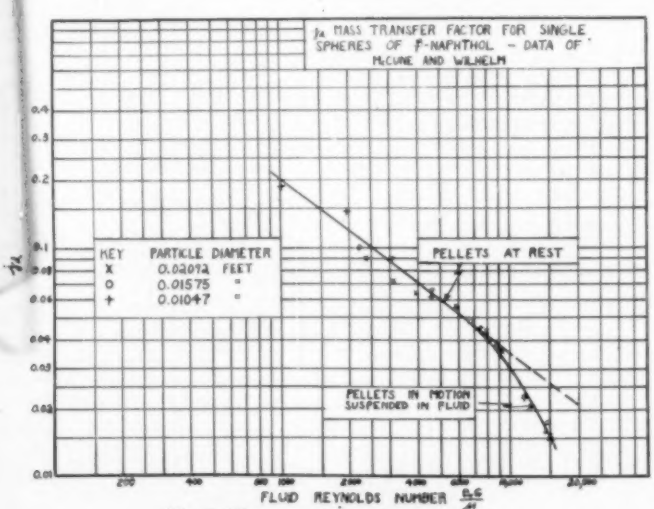

j_h MASS TRANSFER FACTOR FOR SINGLE SPHERES OF β-NAPHTHOL — DATA OF McCUNE AND WILHELM
KEY PARTICLE DIAMETER
X 0.02092 FEET
O 0.01575 "
+ 0.01047 "
PELLETS AT REST
PELLETS IN MOTION SUSPENDED IN FLUID
j_d
FLUID REYNOLDS NUMBER $\frac{DG}{\mu}$

Fig. 7. Mass transfer for single spheres.

as the modified Reynolds number ($6G/a\mu\phi_{es}$) which was also employed in the correlations proposed in the first section of this paper.

The thermal and physical properties of the particles in no way influence the fundamental convection transfer coefficients between fluid and particle such as developed earlier. Similarly for a given effective film thickness a change in the thermal conductivity, density or specific heat of a given size and shape of particle will not influence the rate of heat transfer from the exchanger surface to the fluid stream. What will occur is that the temperature on the surface of the particle and the internal particle temperature gradient will vary. This is probably true with one major exception and that is where the variation in the particle density causes a change in the aggregative tendencies of the fluidized solids and a resultant change in the shape factor. Accordingly, changes in the particle properties for a specific modified Reynolds number, as defined above, will always result in a constant rate of heat transfer.

Since the transfer phenomena are occurring through a film associated with the exchanger surface, the fundamental correlating unit should be based upon transfer coefficients evaluated from the exchanger surface. It was pointed out earlier that the modified Reynolds number ($6G/a\mu\phi_{es}$) was indicative of the degree of disturbance of the normal fluid flow. It is, therefore, postulated that the change in the heat-transfer coefficient from normal flow to the fluidized state is related to the modified Reynolds number. If the heat-transfer coefficient calculated on the basis of an empty tube and the average fluid properties is denoted by h and the actual heat-transfer coefficient in the presence of particles as h_T, the incremental change in the heat-transfer coefficient can be defined as:

$$h_p = h_T - h \qquad (25)$$

The j heat-transfer factor may be defined in terms of h_p as

$$j_{hp} = \frac{h_p}{C_p G}\left(\frac{C_p \mu}{k}\right)_f^{2/3} \qquad (26)$$

In view of the independent effect of void fraction, ϵ, over and above its relationship to the total particle surface area per unit volume of reactor as defined by Equation (9) for heat and mass transfer between the main gas stream and the bed, it appears that the solid concentration will also be an independent variable for transfer through exchanger surfaces.

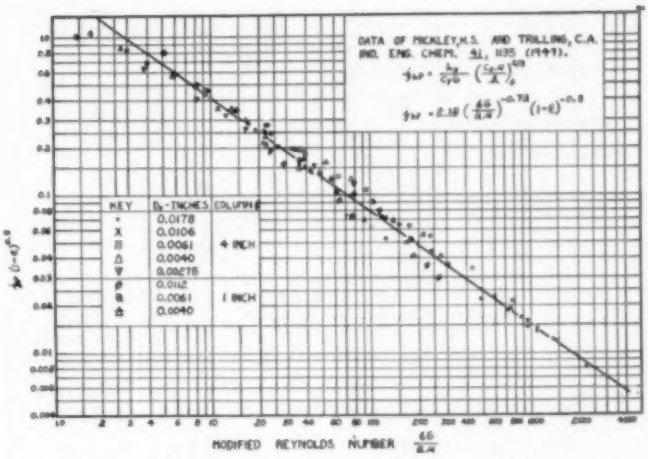


Fig. 8. Particle heat-transfer J_{hp} for externally heated fluidized beds.

The available data in the literature to test the concepts presented above are meager. Only two publications are available—that by Mickley and Trilling (*11*) and one by Levenspiel and Walton (*8*). Data of the latter paper cannot be tested in the proposed method of correlation because of insufficient information on void volumes, etc. However, data (*11*) are quite satisfactory for this method of correlation. Since this paper was written, a paper by Leva, dealing with this subject appeared (*7*a). These data primarily cover a region where aggregative fluidization takes place. Insufficient data exist to correlate categorically the shape factor for aggregative fluidization as a function of the fluid and particle properties.

Mickley and Trilling studied heat-transfer conditions in fluidized beds of spherical particles ranging in size from 0.0016 to 0.0178 in. in diameter. The particles were Scotchlite glass beads having absolute particle densities of 177-151 lb./cu.ft. Fluidization occurred in an air stream and in vertical beds 1 to 4 in. in diameter and 4 to 8 ft. high. Heat was transferred by means of electric energy through the tube walls or through the wall of a cylindrical heating element inserted axially in the bed. The

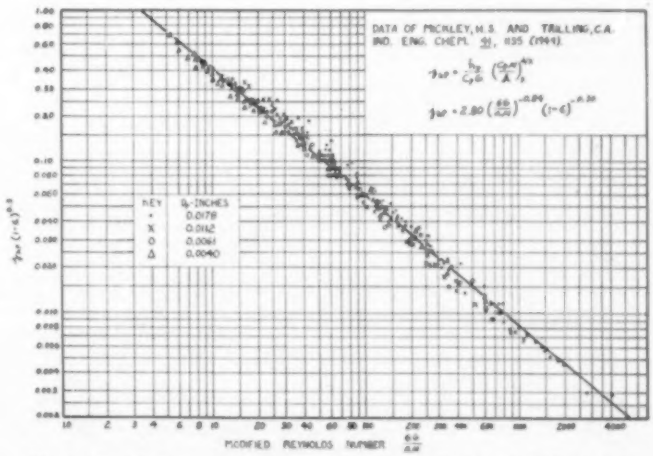


Fig. 9. Particle heat-transfer factor J_{hp} for internally heated fluidized bed.

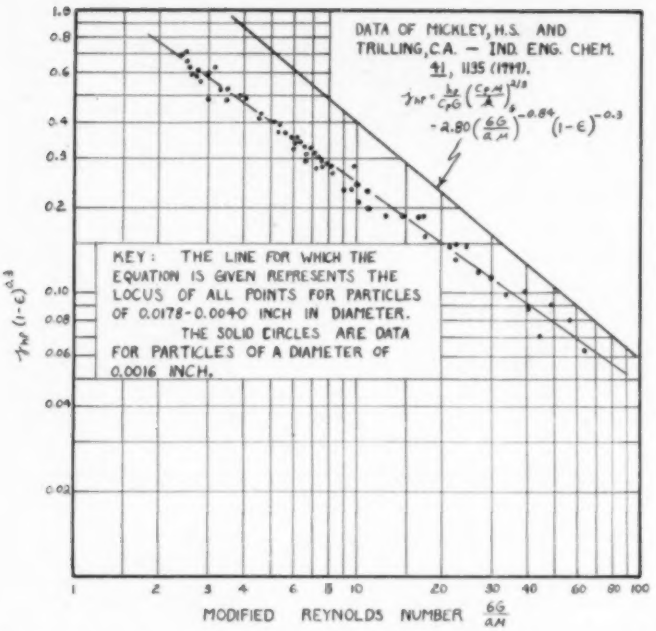

DATA OF MICKLEY, H.S. AND TRILLING, C.A. — IND. ENG. CHEM. 41, 1135 (1949).
KEY: THE LINE FOR WHICH THE EQUATION IS GIVEN REPRESENTS THE LOCUS OF ALL POINTS FOR PARTICLES OF 0.0178-0.0040 INCH IN DIAMETER. THE SOLID CIRCLES ARE DATA FOR PARTICLES OF A DIAMETER OF 0.0016 INCH.
MODIFIED REYNOLDS NUMBER

Fig. 10. Particle heat-transfer factor J_{hp} for 0.0016-in. particles for an internally heated fluidized bed.

solid concentration was varied from a minimum of 1.6% to a maximum of 52%. Special attention was given in the design of the experimental equipment to eliminate radiation to the particles from the exchanger surface. In view of this, the heat transfer may be considered as typical of convective transfer only.

Data of the above investigation were recalculated in terms of j transfer factors both as j_{hp} and j_{hT}. Heat-transfer coefficients for fluid flow in empty tubes were calculated from existing standard correlations (*9*). The j_{hT} factor denotes the evaluation of a heat-transfer j factor using the total heat-transfer coefficient. These j factors were related to the modified Reynolds number without reasonable correlation. As suspected earlier, an independent effect upon the transfer factor, due to the population of the solid particles, was observed. When the correlation was modified to include this effect, satisfactory agreement was obtained.

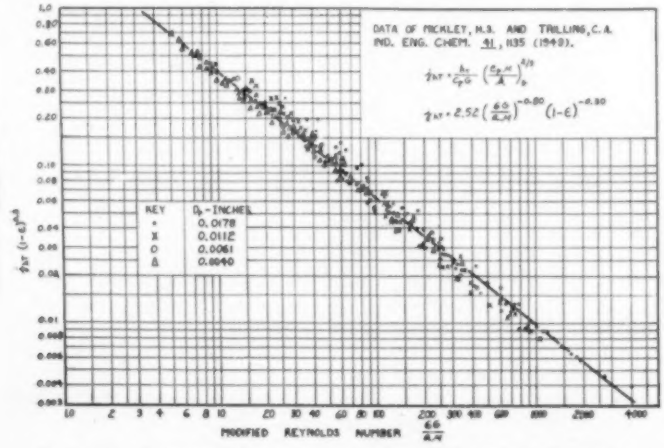


Fig. 11. Total heat-transfer factor J_{hT} for internally heated fluidized bed.

Figure 8 shows a relationship of the particle heat-transfer factor, j_{hp}, for externally heated fluidized beds. Experimental data for both columns of 1 in. and 4 in. in diameter and particle diameters of 0.0040-0.0178 in. all are within an approximate maximum deviation of about ±20% of the best line. The deviations are not orderly for any specific variable. In these calculations, the shape factor was assumed as unity; that is, no agglomeration for the spheres occurred. This is best expressed as:

$$j_{hp} = 2.18\left(\frac{6G}{a\mu\phi_{es}}\right)^{-0.72}(1-\epsilon)^{-0.30} \qquad (27)$$

Figure 9 illustrates the type of correlation obtained when the data for the four largest particle sizes in the internally heated fluidized beds are plotted. Data for the smallest size will be discussed independently. The correlation is good and, again, substantially all the data are within ±20% of the best curve which can be expressed by Equation (*28*).

$$j_{hp} = 2.80\left(\frac{6G}{a\mu\phi_{es}}\right)^{-0.84}(1-\epsilon)^{-0.30} \qquad (28)$$

Equation (*28*) is based upon a Calrod exchanger 0.491 in. in diameter and an inside tube diameter of 2.875 in. The major difference in Equations (*27*) and (*28*) are in the coefficients and the exponents on the modified Reynolds number. These variations probably are due to two factors. First, in normal fluid flow the correlations for annular exchangers include an effect of the ratio of the inside tube diameter to the outside tube diameter. This effect may also be encountered when heat is exchanged in the presence of particles. Secondly, and what is perhaps of even greater significance, is the change in the temperature profile and film thickness due to the annular space at a constant modified Reynolds number. This may result from differences in the character of the fluidization. Further experimental evidence along these lines is required.

Figure 10 presents the data for the heat-transfer factor, j_{hp}, for the 0.0016-

in. particles of Mickley and Trilling in their internally heated exchanger. A correlation exists for these data which, however, is not in concordance with the generalized Equation (28) for the larger size particles when the shape factor is taken as unity. Observation of the points in Figure 10 may be taken as an indication that agglomeration of the small particles employed are taking place and that the agglomerating tendency decreases at high modified Reynolds numbers. The agglomerating effect apparently becomes negligible at modified Reynolds numbers above about 100. The shape factors required to bring these data in agreement with Equation (28) vary from about 0.8, at an Re_M of 60, to 0.4, at an Re_M of 2. This is equivalent to an increase in the effective particle diameter of about 25% to 150%, respectively. The agglomerating tendency, therefore, increases at a given modified Reynolds number as the particle diameter decreases. It also increases as the population or solid concentration increases and becomes smaller as the mass velocity increases.

Figures 11 and 12 illustrate the type of correlation obtained for the total heat-transfer factor j_{hT} for internally heated and externally heated fluidized beds respectively. Equations (29) and (30) represent the data within about a maximum deviation of ±20%.

Total heat-transfer factor for internally heated fluidized beds:

$$j_{hT} = 2.52\left(\frac{6G}{a\mu\phi_{es}}\right)^{-0.80}(1-\epsilon)^{-0.20} \tag{29}$$

Total heat-transfer factor for externally heated fluidized beds:

$$j_{hT} = 2.00\left(\frac{6G}{a\mu\phi_{es}}\right)^{-0.69}(1-\epsilon)^{-0.20} \tag{30}$$

Although satisfactory agreement is found, this method of correlation is valid in the case of high gas loadings only. In the limit, at zero solid concentration, an equation, such as (29) or (30), results in a zero heat-transfer coefficient. This is impossible as the transfer coefficient remains finite and is equal to that for normal fluid flow at the appropriate Reynolds number. In contrast to this anomaly, the method of correlation proposed for the particle heat-transfer coefficient results in no discontinuities or ambiguous results at either zero or unity for the void volume. The apparent correlation for the total heat-transfer j factor is due to the slight difference between the total heat transfer coefficient and the contribution due to the presence of particles. The difference in more than 90% of the data is within the experimental accuracy of the measured transfer coefficient.

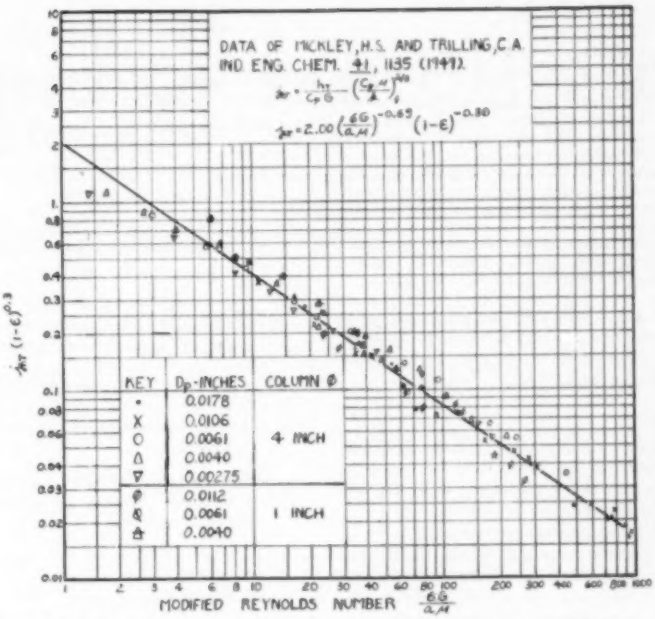

DATA OF MICKLEY, H.S. AND TRILLING, C.A.
IND. ENG. CHEM. 41, 1135 (1949).
$j_{hT} = \frac{h_T}{c_p G}\left(\frac{c_p \mu}{k}\right)^{2/3}_f$
$j_{hT} = 2.00\left(\frac{6G}{a\mu}\right)^{-0.69}(1-\epsilon)^{-0.20}$
$j_{hT}(1-\epsilon)^{0.3}$
KEY | D_p-INCHES | COLUMN Ø
• | 0.0178 |
X | 0.0106 |
O | 0.0061 | 4 INCH
Δ | 0.0040 |
▽ | 0.00275 |
φ | 0.0112 |
& | 0.0061 | 1 INCH
⏃ | 0.0040 |
MODIFIED REYNOLDS NUMBER $\frac{6G}{a\mu}$

Fig. 12. Total heat-transfer factor J_{hT} for externally heated fluidized beds.

Discussion of Correlation

Equations (27) and (28) are the recommended expressions to employ for externally and internally heated fluidized beds, respectively. These use particle heat-transfer coefficients. In the absence of more comprehensive data on the ratio of internal heater diameter to outer tube diameter, it is suggested that no allowance be made for the variation in annulus as other ratios are employed. This appears satisfactory as a first approximation at least, in view of the small difference in Equations (27) and (28).

It is well to point out that the exponent on the solid volume factor, $(1-\epsilon)$, is not too critical. Equally good correlation is obtained when an exponent of 0.2, rather than 0.3, is used. This necessitates, however, a corresponding shift in the exponent on the modified Reynolds number. It is anticipated that the same grouping of variables will correlate data in fluidized systems when other types of interchangers are employed. Different coefficients and exponents will, however, result.

Of particular interest is the observation that the normal flow in the absence of particles for the data of Mickley and Trilling would cover viscous, transition and highly turbulent flow. In contrast, the recommended correlations in the presence of particles show no breaks or transitions over the range of modified Reynolds numbers studied.

Equations (27) and (28), as well as those recommended in the first part of this paper, may be rearranged to show the total effect of solid concentration. For spherical particles, Equation (9) relates the solid volume fraction to the surface area. By rearranging, $(1-\epsilon)$ may be removed from the modified Reynolds number and combined with the particle population term in Equations (27) and (28). In the general case of irregular particles, where a nominal particle diameter is used, the Carman shape factor, ϕ_s, and defined by Equation (19), should be included. Thus, Equations (27) and (28) can be transformed respectively into:

$$j_{hp} = 2.18\left(\frac{D_p G\phi_s}{\mu\phi_{es}}\right)^{-0.32}(1-\epsilon)^{0.42} \tag{31}$$

$$j_{hp} = 2.80\left(\frac{D_p G\phi_s}{\mu\phi_{es}}\right)^{-0.56}(1-\epsilon)^{0.54} \tag{32}$$

Mickley and Trilling correlated their data on the basis of total heat-transfer coefficients by the following Equations (33) and (34) for internally and externally heated fluidized beds respectively:

$$h_T = 0.0433\left(\frac{\rho_M^2}{D_p^3}\right)^{0.333} \tag{33}$$

$$h_T = 0.0118\left(\frac{\rho_M G_o}{D_p^3}\right)^{0.333} \tag{34}$$

Where

ρ_M = solid concentration in fluidized mixture, lb./cu.ft.

G_s = superficial mass velocity, lb./(sq. ft.)(hr.)
D_p = particle diameter, ft.
h_T = heat-transfer coefficient, B.t.u./(hr.)(sq.ft.)(° F.)

They report agreement for most of the data within ±25%. These equations are essentially empirical, are not dimensionless and cannot be used for extrapolation to other solids, fluids or equipment sizes. In contrast, correlations presented in this report are dimensionless, rational and are probably capable of extension to other fluid systems both gaseous and liquid, and independent of thermal conductivity, specific heat and density of the fluidized solid.

Mass Transfer. An analogous equation to (25) may be written for mass transfer to fluidized systems from transfer surfaces. Thus,

$$k_p = k_T - k \qquad (35)$$

where k is the mass-transfer coefficient under normal flow with no particles present, k_T is the actual mass-transfer coefficient in the presence of solids and k_p is the incremental change in the transfer coefficients. All transfer coefficients are calculated on the basis of the exchanger area and not the particle area. It is postulated that the ratio of j_h/j_d remains equal to 1.076 for transfer from surfaces to the fluid stream in a manner similar to that developed earlier for transfer phenomena direct from the fluid stream to the particle. It is, therefore, possible to develop the following equations for mass transfer between internal-transfer and external-transfer surfaces respectively:

$$j_{dp} = 2.03\left(\frac{6G}{a\mu\phi_{cs}}\right)^{-0.72}(1-\epsilon)^{-0.3} \qquad (36)$$

$$j_{dp} = 2.61\left(\frac{6G}{a\mu\phi_{cs}}\right)^{-0.94}(1-\epsilon)^{-0.3} \qquad (37)$$

Transformations similar to Equation (31) may also be developed for mass transfer.

Acknowledgment

Appreciation is given to the encouragement, suggestions and criticisms of Prof. O. A. Hougen and Prof. K. M. Watson.

Notation

a = effective area of heat or mass transfer per unit volume of reactor
A_p = effective surface area of a particle
C_p = specific heat
D_p = equivalent particle diameter
D_v = diffusivity of fluid
f' = modified friction factor, dimensionless
G = superficial mass velocity of fluid based upon total cross-sectional area
g_c = gravitational constant
h = heat-transfer coefficient
j = dimensionless transfer factor
k = mass-transfer coefficient
k = thermal conductivity of fluid
$K_{\Delta p} = (Re_M)^2 f'$
L = bed height
L_0 = bed height at zero fraction void
M_m = mean molecular weight of fluid
q = rate of heat transfer
Re_M = modified Reynolds number, dimensionless
u = linear velocity
V = volume of reactor
w = rate of mass transfer
$(\Delta 1)_m$ = mean potential difference from fluid stream to the interface
ΔP = pressure drop
$(\Delta t)_m$ = mean temperature difference from fluid stream to the interface

GREEK:

ϵ = void fraction, dimensionless
ρ = density of fluid
ϕ_{cs} = shape factor, dimensionless
ϕ_s = shape factor by Carman, dimensionless
ξ = mean value of the inert non-transferable component
μ = viscosity of fluid

SUBSCRIPTS:

d = mass transfer
f = film conditions
h = heat transfer
m = mean conditions for property under consideration
p = particle
T = total transfer coefficient, or tube when used as subscript on diameter (D)

Literature Cited

1. Blake, F. C., *Trans. Am. Inst. Chem. Engrs.*, **14**, 415 (1922).
2. Carman, P. C., *Trans. Inst. Chem. Engrs. (London)*, **15**, Part 1, 150 (1937).
3. Colburn, A. P., *Trans. Am. Inst. Chem. Engrs.*, **29**, 174 (1933).
4. Gamson, B. W., Thodos, G., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **39**, 1 (1943).
5. Hobson, M., and Thodos, G., presented at the Tulsa regional meeting A.I.Ch.E. (1949).
6. Hurt, D. W., *Ind. Eng. Chem.*, **35**, 522 (1943).
7. Kozeny, *Ber. Wien Akad.*, **136a**, 271 (1927).

7a. Leva, Max, *Chem. Eng. Progress*, **45**, 563 (1949).

8. Levenspiel, O., and Walton, J. S., *Heat Transfer and Fluid Mechanics Inst. (ASME)*, 139 (1949).
9. McAdams, W. H., "Heat Transmission," McGraw-Hill Book Co., New York (1942).
10. McCune, L. K., and Wilhelm, R. H., *Ind. Eng. Chem.*, **41**, 1124 (1949).
11. Mickley, H. S., and Trilling, C. A., *Ind. Eng. Chem.*, **41**, 1135 (1949).
12. Morse, R. D., *Ind. Eng. Chem.*, **41**, 1117 (1949).
13. Resnick, W., and White, R. R., *Chem. Eng. Progress*, **45**, 377 (1949).
14. Taecker, R. G., and Hougen, O. A., *Chem. Eng. Progress*, **45**, 188 (1949).
15. Taecker, R. G., Private communication (June, 1949).
16. Wilke, C. R., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **41**, 445 (1945).

Discussion

Anonymous: Do you think that surface roughness would have any particular effect on the shape factor for any given shape packing?

B. W. Gamson: The effect of surface roughness on the shape factor for a specific type of packing will vary depending upon the type of protuberance. If the latter does not appreciably affect the particle surface area and type and number of particle contacts, no significant effect will be observed. If the protuberances significantly modify either surface area and/or contacts, the shape factor will be changed.

Anonymous: Have you noticed any relationship between the bed diameter and the mass-transfer coefficient? In some of our work we have noticed that predicted transfer has been a much lower one.

B. W. Gamson: No, I have not.

(*Presented at Forty-second Annual Meeting, Pittsburgh, Pa.*)

SPRAY DRYING OF SANTOMERSE

JU CHIN CHU†, L. E. STOUT, and R. M. BUSCHE

Washington University, St. Louis, Missouri

Spray drying of Santomerse No. 1 was investigated in a laboratory spray dryer. The study covers the effects of operating variables upon bulk density and moisture content of the dried product. Operating characteristics investigated were (1) the addition of organic solvents (acetone and methanol); (2) temperature of the feed; (3) concentration of the feed; (4) atomizing pressure, and (5) temperature of the drying medium.

Product characteristics are correlated as a function of the operating variables studied and their relation is discussed.

SPRAY drying is a process by which the solids are recovered from liquid solution or slurry by spraying the liquid into a stream of drying gas under such conditions that the recovery of a dry product is permitted. It results in a high rate of drying and therefore is applicable especially to heat-sensitive material.

The mechanism of spray drying has been well covered in the literature (*1, 2, 4, 9, 13*). Bulk density and moisture content are two main concerns of the spray-dried product. Jones (*6*) reported the effect of feed concentration on the bulk density of the spray-dried soap. Reavell (*12*) made a study of the effect of feed concentration and atomizer speed on the bulk density. Using a sodium silicate solution, Lamont (*8*) found that the bulk density decreased with an increase in concentration which is not in line with the findings of Jones and Reavell. Lamont also found that an increase in gas temperature decreased bulk density of spray-dried soap. In the spray drying of milk, Waite (*14*) found that the temperature of the feed had little effect on the properties of dried particles. Recently, Boggs and Fevold (*2*) and Greene et al (*5*) reported the effect of different operating variables upon the properties of the spray-dried white-egg powder including the moisture content which determines the stability of the latter.

Santomerse No. 1 (*11*), an alkyl aryl sulfonate, is a synthetic detergent and wetting agent with numerous applications. In the process of its manufacture, Santomerse No. 1 is finally drum-dried at roll temperature not higher than 250-260° F. Due to its inherent advantages, spray drying of Santomerse has been tried.

† Present address: Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Experimental Methods

Brief Description of Flow Sheet (Shown in Fig. 3). The dryer used in this work was a Turbulaire Laboratory spray dryer, Type *N-2*, Model 4-25-*E*, built by the Western Precipitation Corp., Los Angeles, Calif. Figure 1 shows an over-all view of the dryer in operation.

The material to be spray-dried was supplied by means of the low air-pressure feed system to the atomizing nozzle situated near the top of the desiccator. The atomization occurred in the desiccator just beyond the nozzle tip in the downward moving hot-air stream. This hot air was drawn from the room and was heated to the desired temperature by the air heater. For extreme cleanliness an air filter was placed ahead of the heater. The air flow was maintained by the centrifugal fan located between the desiccator and the cyclone separator.

In the multiclone collector, the bulk of the powder was removed from the air stream and was collected in the multiclone hopper. Any remaining powder in the air leaving the multiclone was caught in the bag filters.

Description of Equipment. The desiccator consisted of a 3-ft. long cylindrical portion of 4 ft. I.D. with a 60° conical bottom, and was capped by a 135° conical top with turret-type hot-air inlet at the top of the cone. The over-all height of the desiccator, with feed assembly, was approximately 10½ ft. The hot-air inlet opening below the turret top was slightly above the level of the base of the upper cone, so that the atomizer level was approximately on a level with the upper cone base. All the product passes through the fan.

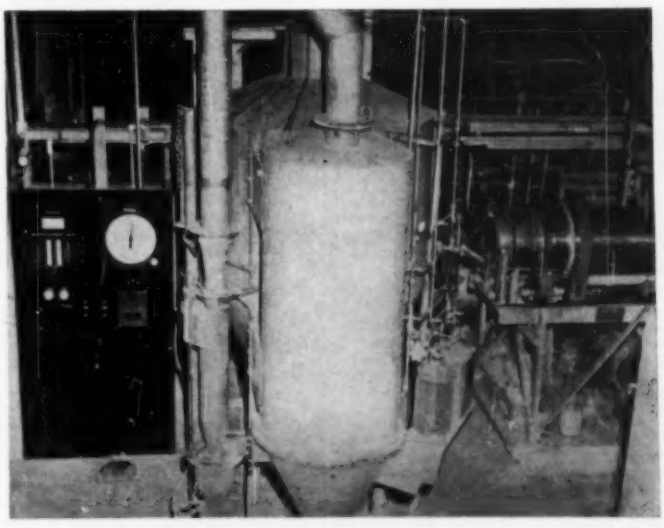


Fig. 1. Over-all view of spray dryer.

TABLE 1

Bulk Density and Moisture Content of Products for Various Inlet Gas Temperatures

Feed – 20% aqueous solution of Santomerse #1
Feed Rate – 0.485 lbs/min.

Inlet Gas Temperature °F	Bulk Density ($gm/in.^3$) at Atomizing Pressure Psig		% Moisture (Dry Basis) Content at Atomizing Pressure Psig	
	19	38	19	38
350	5.30	6.64		
400	5.46	5.72	3.61	3.62
	5.35	5.32	3.66	5.44
450	4.53	4.81	2.97	3.67
			2.77	3.27
500	4.03	4.63	2.84	3.22
	4.52	4.26	2.93	
550	3.12	3.98	2.06	2.85
	4.18	3.87	2.38	
600	3.64	3.05	1.40	
650	3.43	2.71	1.88	2.24
	3.24	3.09		2.00
700	3.03	2.09	1.74	1.50
	3.31	2.39		
750	2.69	2.31	1.15	1.30
		2.19	1.03	
800	2.21	2.16	1.08	1.60
		1.93	1.37	1.34
				1.69
850	2.06	1.89	1.03	1.50
	2.23	2.03		1.36
				1.30
900	2.16	1.82	1.18	1.20
				1.11
950	2.17	1.89	0.899	0.87
		1.70	0.53	
1050	2.34	1.83	1.10	0.97

TABLE 2

Bulk Density and Moisture Content of Product at Various Concentrations and Temperatures of Feed Solution

Inlet Gas Temperature – 600°F.
Feed Rate – 0.485 lbs/min.

Feed Conc. (% Solids)	Feed Temp. (°F.)	Air Pressure (Psig.)	Bulk Density ($g./in^3$)	% Moisture (Dry Basis)
5	70	38	1.7920	1.31
	70	19	2.3459	1.62
	125	38	3.2385	2.03
	125	19	2.3343	2.89
	180	38	1.9180	1.62
	180	19	1.3178	2.08
10	70	38	1.9149	0.98
	70	19	1.9374	0.89
	125	38	2.7235	2.03
	125	19	3.5409	1.54
	180	38	0.9418	1.20
	180	19	1.4976	1.93
15	70	38	2.0231	0.63
	70	19	2.0496	1.10
	125	38	2.3958	0.85
	125	19	1.7948	2.38
	180	38	1.2438	1.22
	180	19	1.9198	2.68
20	70	38	1.7777	0.98
	70	19	2.6179	1.26
	125	38	2.3751	1.20
	125	19	2.9233	1.81
	180	38	2.0932	1.21
	180	19	1.7992	1.15
25	70	38	3.1330	0.94
	70	19	4.4343	0.85
	125	38	2.8099	0.87
	125	19	3.4009	0.67
	180	38	2.6685	1.04
	180	19	3.6301	0.64
30	70	38	3.3742	0.60
	70	19	3.8247	0.99
	125	38	2.9366	0.86
	125	19	2.5728	1.49
	180	38	3.1138	0.67
	180	19	3.5470	1.16
35	70	38	1.2629	2.00
	70	19	1.6363	1.43
	180	38	3.1393	1.45
	180	19	3.0897	3.11

Fan. The air flow through the spray-dryer installation was produced by a centrifugal fan driven by a three-phase, 60-cycle, 220-v., 1½-hp., 3450-rev./min. electric motor.

Powder Collecting System (*See* Fig. 2). The primary powder collection was accomplished by means of a 61-F multiclone. The volume flow through the collector can be determined from the water manometer deflection and the equation

$$Q = 4.5\sqrt{HT} \qquad (1)$$

The residual powder contained in the air leaving the multiclone was vented to atmosphere.

Temperatures of the drying gas ranged from 300 to 1200° F. The drying gas was heated by a gas furnace.

Drying-gas temperature was regulated by a Brown electronic potentiometer pyrometer involving a circular chart, air-activated controller, push-button standardization and throttler control. Its primary measuring element was an iron-constantan thermocouple, installed in the hot-air duct to the desiccator.

The following data were observed and recorded for each run on the spray dryer:

a. Inlet gas temperature from controller (3). Inlet gas wet- and dry-bulb temperature from thermometers (19).
b. Exit gas temperature from thermometer (20). Exit wet-bulb temperature (21).
c. Feed rate from rotometer (14).
d. Feed temperature.
e. Cyclone draft from manometer (22).
f. Nozzle air pressure from gauge (23).
g. Barometric pressure.

Analysis

A. *Bulk Density.* The apparatus used for determining the bulk density consisted of a stainless steel cup of 1-cu.in. volume filled by pouring the sample through the glass baffle arrangement into an open-bottomed hopper and thence into the cup. The surface of the cup was leveled off with a spatula. Three bulk-density determinations of each sample were made.

B. *Moisture Content.* Aluminum beakers, 2 in. in diameter, and 2⅜ in. in height, were used to hold the samples which were dried in an air oven at a temperature of 105° C. until successive weighings over one-hour periods showed the moisture content to vary less than 0.1%.

C. *Surface Tension.* The surface tension of a 20% Santomerse slurry was determined for various temperatures. The change of surface tension with the addition of various organic solvents and of acetone and methanol individually at their different concentrations to the feed was also determined by a DuNony tensiometer. Little change of surface tension with the operating conditions was noted.

D. *Viscosity.* Determination of the viscosity of the various feed solutions studied was accomplished with an Ostwald pipette according to Pouiselle's method (10). The accuracy of this determination of viscosity was checked by measuring the viscosity of C.P. benzene and C.P. ethyl alcohol, indicating an accuracy within 1%.

E. *Water Balance.* Water balance over the dryer was obtained by measuring the following: (1) mass rate of flow of dry gas through the dryer; (2) rate of flow of the feed, and (3) the humidity of the inlet and exit gas.

The over-all accuracy, measured by the reproducibility of the results, is within ±5%.

Experimental Results

In the present investigation, the feed rate to the spray dryer was maintained constant at 0.485 lb./min. A 20% aqueous solution of Santomerse No. 1 was spray-dried at two atomizing pressures (air pressure) 19 and 38 lb./sq.in. gage, using different inlet gas temperatures ranging from 350 to 1050° F. Bulk densities and per cent moisture contents on a dry basis were determined and are presented in Table 1.

With inlet gas temperatures maintained constant at 600° F., the feed solution of Santomerse containing 5, 10, 15 and 20% of the latter at three different feed temperatures—70, 125 and 180° F.—were spray-dried at two atomizing pressures, 19 and 38 lb./sq.in. gage respectively. Bulk densities and per cent moisture contents were determined and listed in Table 2.

At a constant inlet gas temperature of 600° F., a 20% solution of Santomerse was spray-dried under different atomizing pressures ranging from 10 to 60 lb./sq.in. gage. Bulk densities and moisture contents of the dried products were determined and presented in Table 3. Water balance in each run was determined and listed in the last column in the same table. It is noted that average water balance expressed in terms of per cent decrease of water on the basis of its input is within 5%.

Using a 20% feed solution of Santomerse No. 1 with inlet gas temperature maintained constant at 600° F., the effects of the addition of 5% different organic solvents on the products characteristics were studied at two atomizing pressures 19 and 38 lb./sq.in. gage. The experimental results are shown in Tables 4*a* and 4*b*.

The measured densities of a 20% aqueous solution at different temperatures (3) are omitted here. In Table 5 are listed the measured values of viscosities and surface tension of a 20% Santomerse solution at 18.3° C. and the vapor pressure of different organic solvents in a pure state at 120° C. The density and viscosities of a 20% Santomerse feed solution at different temperatures were also measured, and are presented in Table 6. Variation of densities and viscosities at a constant temperature with the concentration ranging from 5% to 30% were measured and are listed in Table 7. The effect of the concentration of methanol added to the feed solution of 20% Santomerse on the bulk densities of the finally spray-dried products was studied. Experimental results are presented in Table 8, together with the vapor pressure of methanol from the liquid mixture at 49.4° C., viscosities and surface tensions at 18.3° C. In Table 9 the experimental results of the spray drying from a feed containing different concentrations of acetone are similarly presented. In both cases the temperature of the feed was maintained constant at 70° F. during each experiment. Inlet gas temperature at 600° F. and an atomizing pressure at 38 lb./sq.in. gage were used.

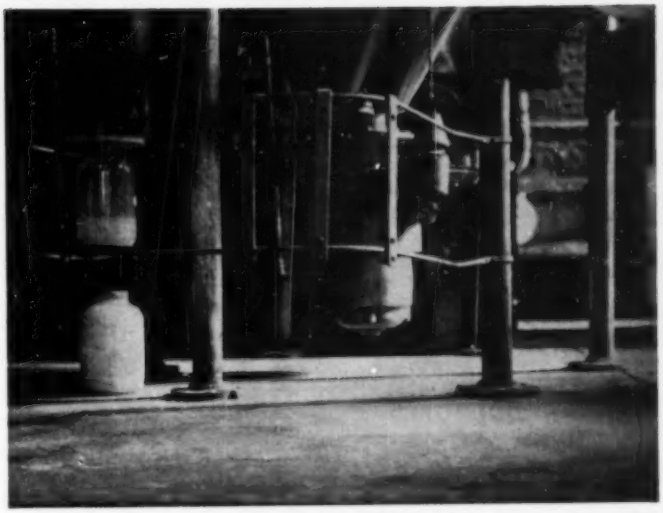


Fig. 2. Collection unit.

Discussion

Effect of Inlet Gas Temperatures. From Table 1, per cent moisture contents and bulk densities of the spray-dried product versus gas-inlet temperature at two atomizing pressures were plotted in Figures 4-7. The general shape of the curves which is the same

TABLE 3

Bulk Density and Moisture Content of Product for Various Atomizing Pressures

Inlet Gas Temperature - 600°F.
Feed Rate - 0.485 lbs/min.
Feed - 20% Aqueous solution of Santomerse #1

Atomizing Pressure (Psig)	Bulk Density (gm/in³)	% Moisture (Dry Basis)	Water Balance (% Decrease)
10	2.9363	1.14	1.96
10	4.0009	0.96	2.40
10	3.2087		
20	2.9889	1.04	1.72
20	2.1127	0.71	4.51
30	2.5458	0.526	2.62
30	2.2013	0.995	5.32
40	2.3121		2.03
40	2.3755	0.948	4.00
50	2.6296	0.82	2.38
50	2.8867	1.06	0.49
50	2.2731	1.14	5.82
60	2.2312	0.58	1.11
60	2.2379	1.38	4.30

TABLE 4a

Bulk Density and Moisture Content of Products with the Addition of 5% Organic Solvent to the Feed Solution

Inlet Gas Temperature - 600°F
Feed Rate - 0.485 lbs/min.
Feed - 20% Aqueous Solution of Santomerse #1

Organic Solvent	Bulk Density (g/in³) at Atomizing Pressure psig 38	19	% Moisture Content (Dry Basis) at Atomizing Pressure 38	19
Tert. Butyl Chloride	1.2207		5.70	
n-Butyl Acetate	3.5479	2.3455	1.77	2.51
Aniline	2.1951	1.7818	2.06	3.36
o-Dichloro Benzene	2.1852	2.8278	1.09	1.29
Ethyl Acetate	1.1316	1.8613	1.24	1.65
Carbon Disulfide	2.0077	2.8674	1.36	1.01
Benzene	1.6707	2.0996	1.28	2.37
Toluene	1.2444	1.8070	1.69	1.55
Furfuryl Alcohol	1.8439	1.7511	1.16	1.52
Ethylene Glycol	1.8439	2.6502	2.13	2.14
Methyl Isobutyl Ketone	3.6146	3.0672	1.42	1.55
Dimethyl Sulfolane	2.3062	3.0060	3.24	2.85
n-Butyl Alcohol	1.8541	1.5572	1.05	1.04
Dioxane	1.2276	1.5949	1.97	1.04
Ethanol	0.9453	1.8251	1.38	2.08
Pyridine	1.8018	1.2218	0.76	.87
o-Toluidine	3.3066	3.2508	0.62	0.92
o-Xylene	1.2647	1.4243	0.89	0.69
Ammonium Hydroxide	2.2786	2.4357	1.39	1.51
Soluble Starch	2.8430		2.68	

TABLE 4b

Bulk Density and Moisture Content of Product with the Addition of 5% Organic Solvents to the Feed Solution at Atomizing Pressure of 38 Psig.

Entering Air Temperature....600°F.
Feed Rate.....0.485 lbs/min.
Feed.....20% Aqueous Solution of Santomerse #1

Organic Solvent	Bulk Density (G/in^3)	% Moisture (Dry Basis)	Water Balance (% Decrease)
Ethyl bromide	3.0725	0.950	5.67
Carbon tetrachloride	2.0544	0.485	
Methyl Alcohol	1.8537	1.21	2.31
Isopropyl Alcohol	1.1597	0.636	4.98
Trichloro ethylene	2.0835	1.11	
Chloroform	2.1831	0.695	5.65
Ethyl Ether	1.5068	1.26	5.48
Acetone	1.2769	0.867	3.08
Mono-chloro-benzene	2.5103	0.620	1.22
Ethylene Chloride	1.9856	1.11	4.48
N-amyl Alcohol	3.7519	0.45	2.67

TABLE 5

Viscosity and Surface Tension of 20% Santomerse Feed with the Addition of 5% Organic Solvent

Solvent added	Viscosity (cp) 18.3°C	Surface Tension 18.3°C dynes/cm	Vapor Pressure of Pure Solvent 120°C
Ethyl bromide	1.432	27.6	6658
Carbon disulfide	1.444	30.0	5240
Pyridine	1.590		795
Soluble starch	1.555		
n-butyl acetate	6.270	25.2	900
Ethanol	4.230		3220
n-Butyl alcohol	8.090		1020
o-Dichloro benzene	1.582		40
tert-butyl chloride	1.925		9000
Dimethyl sulfolane	7.300		
Methyl-isobutyl-ketone	1.775	24.5	760
Aniline	1.698		96.6
o-Xylene	1.810		394
Ammonium hydroxide	2.042		
Benzene	1.519		2238
Ethyl acetate	4.260		2585
Toluene	1.948		1020
Dioxane	2.860		1400
Ethylene chloride	2.270	29.9	2220
O-Toluidine	6.650		62.3
Chloroform	2.840	27.8	3926
Ethyl ether	9.000	32.6	7500
Mono-chloro-benzene	2.510	29.5	543
Acetone	3.590	29.4	4547
Trichloroethylene	3.650	30.0	1950
Prim-n-amyl alcohol	2.675	26.5	
Carbon tetrachloride			2390
Furfuryl alcohol			118
Ethylene glycol		29.8	40
Isopropyl alcohol			3600
Methyl alcohol			4750

in these four aforementioned figures, indicates that both bulk density and moisture content are inverse functions of the gas-inlet temperature.

From the per cent moisture content in the finally spray-dried product, it seems obvious that at the lower temperatures drying is less complete than at the higher temperature due to the lower rate of heat transfer. Examination of Figures 4 and 5 reveals the fact that the use of the higher atomizing pressure results in a displacement of the curve toward an increase in moisture content. However, the doubling of atomizing pressures from 19 to 38 lb./sq.in.gage produces little change in moisture content.

The decrease in bulk density with an increase in gas temperature is shown in Figures 6 and 7 for two atomization pressures. Findings confirmed those of Lamont who showed that an increase in gas temperature decreased the bulk density of the spray-dried soap. It appears that at the lower temperatures, particularly, bulk density is a direct function of moisture content. The product of higher moisture would tend to have a higher bulking weight caused by the presence of water which is considerably denser than the dry solid. Because of this greater relative density the presence of moisture tends to diminish the effect of atomization upon bulking weight, so that the curves at 38 and 19 lb./sq.in. gage are synonymous at low temperatures. However, as moisture content approaches a low constant value, the influence of atomization causes the bulk density of the product at the higher pressure to decrease, faster than that at the lower pressure. This is the reverse of the effect of atomization upon moisture.

The greater the temperature difference between liquid drops and gas temperature, the greater the rate of heat transfer, and the greater the degree of expansion of the particle. This effect would also tend to decrease the bulk density by increasing the void space of the product.

Effect of Atomizing Pressure. A decrease in bulk density is caused by an increase in the atomization pressure. Figure 9 shows that as the pressure rises, bulk density rapidly decreases at low pressure and asymptotically approaches a constant value at the higher pressures. Below 20 lb./sq.in. gage the energy of the spray is not sufficient to overcome the forces of surface tension and viscosity which resist disruption of the fluid in the formation of a hollow particle. Consequently, under these conditions, the particles formed are solids of irregular masses, having a high bulk density.

Results concerning the relationship between bulk density and atomizing pressure might be explained in the same way as Lewis's observation on the atomization of water (*9*). The radius of the droplet leaving the atomizer decreases rapidly with the increase of atomizing pressure, finally approaching asymptotically to a constant value, after a certain atomizing pressure. The use of atomizing pressure above this limit which will be a useless expenditure of energy, gives no further decrease of the size of the droplet, which might be a major factor in determining the bulk density of the product while the other operating conditions of the spray drying are maintained constant.

As the force of atomization increases, lighter, hollow, and spherical particles begin to take precedence until the maximum degree of atomization is reached, and a constant bulking weight is approached. Only a slight increase of moisture content with atomization appears, indicating that at the gas temperature used, 600° F., atomizing pressure affects only the shape and size of the particle formed. It is possible, however, that under other operating conditions, i.e., gas temperature, feed rate, etc., the specific effect of atomization upon moisture could be more pronounced. Moisture content may rise with atomization pressure since the rapid expansion of the compressed air would exhibit the Joule-Thompson effect, being considerably cooled and enveloping the particle in a saturated atmosphere of low temperature. Such conditions would initially inhibit the evaporation process until turbulence removed the saturated film. This effect would be more pronounced as the atomization pressure increased, resulting in a slight increase in moisture content.

However, results of the present investigation of the effect of the atomizing pressure on the bulk density of the spray-dried products differ from those of Reavell in the absence of a minimum value of bulk density when the latter is plotted versus atomizing pressure. It might be due to the fact that Santomerse No. 1 used in the present work had little tendency toward disintegration by the explosion of the internal pressure inside the droplets of the liquid. This characteristic of Santomerse No. 1 itself prevents the reduction of the volume of the interstices which will cause the increase of the bulk density of the final product from a spray dryer.

As the atomizing pressure used in this work ranged from only 10 to 60 lb./sq.in. gage, and the Reavell's minimum occurred at about 10,000 rev./min. of the rotating disk used in atomizing the feed, it is possible that sufficiently high atomizing pressure was not used to reach the minimum point of the bulk density of

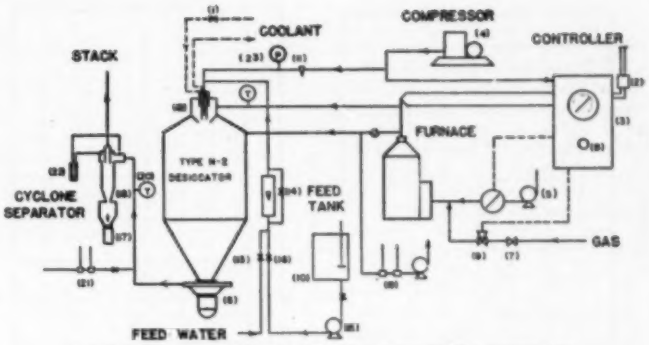


Fig. 3. Flow sheet of Turbulaire spray dryer and its accessories.

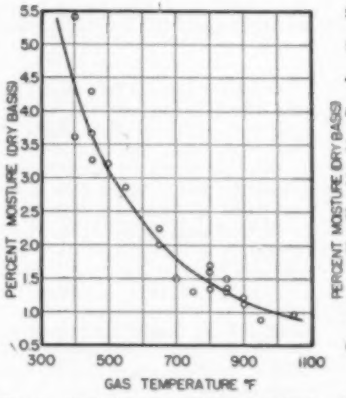


Fig. 4. Variation of moisture content with gas temperature at 38 lb./sq.in. gage.

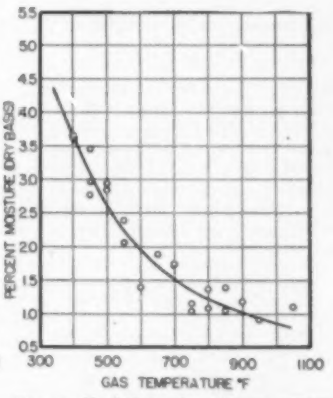


Fig. 5. Variation of moisture content with gas temperature at 19 lb./sq.in. gage.

TABLE 6

Viscosity of Feed at Various Temperatures

20% aqueous solution of Santomerse #1

Temp. °C	Density (g/cc.)	Viscosity Centipoises
65	1.1045	0.834
60	1.1074	0.887
55	1.1100	0.953
50	1.1127	1.03
45	1.1159	1.139
40	1.1180	1.121
35	1.1209	1.35
30	1.1225	1.45
25	1.1246	1.68
20	1.1267	1.85
18.3	1.1273	1.93

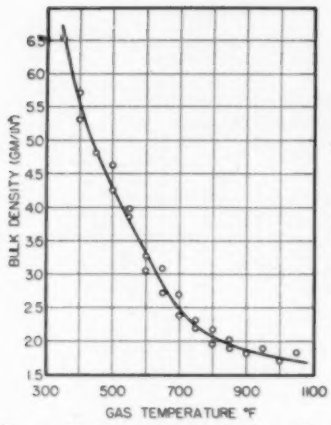


Fig. 6. Variation of bulk density with gas temperature at 38 lb./sq.in. gage.

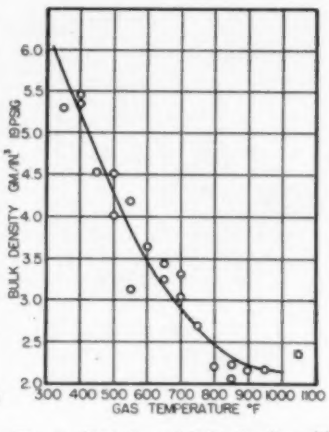


Fig. 7. Variation of bulk density with gas temperature at 19 lb./sq.in. gage.

Reavell. The solubility of the finally dried product is a factor (*4*) limiting the use of high atomizing pressure. At a too high degree of atomization, the particles became coated with a film of adsorbed gas, and were difficult to collect. Subsequently, when mixed with water, they were difficult to wet and to dissolve.

Effect of Feed Temperature and Concentration. Figure 10 indicates the effect of feed concentration on bulk density and moisture content at feed temperatures of 70° and 180° F. Referring to the curves for bulk density, it is noted that an increase in concentration causes an increase in viscosity (Fig. 13), and particles formed at higher concentrations are heavy-walled spheroids finally becoming solid spheres, having a relatively high bulk density. Results here coincide with the results found by Reavell and Jones and differ from those of Lamont.

The relation between bulk density and the viscosity of the feed at the concentrations reported is shown in Figure 11. This clearly shows that density, viscosity, and concentration are directly related each to the other. An increase in the temperature decreases the viscosity of the feed solution, shown in Figure 12. This results in a product of lower density, and the resultant curve is lower than that at the lower temperature. The difference between these two curves is diminished at higher concentrations where the effect of concentration on viscosity is more pronounced than the temperature effect.

The curves of moisture content against concentration show that product moisture is practically a constant value over the range of concentrations used. This would indicate as in the effect of atomization pressure that concentration has a pronounced effect upon the shape-forming characteristics of the fluid to the nozzle, but little effect upon the product moisture. Although a jump in temperature from 70° to 180° F. effects a small difference in products characteristics, there are two distinct curves representing two different temperatures in Figures 10 and 11. This similar behavior toward the temperature of the spraying liquid was also observed by Waite in drying milk (*14*).

Effect of Organic Solvents. It is of importance in examining experimental data to bear in mind that many factors simultaneously enter into the over-all effect upon bulk density and moisture content. This is especially true with the use of organic solvents in the feed having a wide range of viscosity, surface tension, vapor pressure, and other physical properties that may have an important influence upon the drying operation. An analysis of results must always include a consideration of these properties that represent uncontrollable parameters.

The vapor pressure of water at low temperature is not sufficiently high to explode the droplet if its surrounding film is strong. The admixture of ether, alcohol or benzene will supply enough pressure to rupture the film at a relatively low temperature.

With the purpose of finding a generalized correlation between bulk density or moisture content and physical properties of an added volatile compound, such as vapor pressure, latent heat of vaporization, viscosity or surface tension, a variety of solvents of 5% was added to the feed to test their individual effect on the product characteristics after spray drying. The reciprocal of moisture content of the dried product plotted versus the logarithm of vapor pressure of the pure solvent added to the feed results in a straight line which is represented by the following equation; this indicates that an increase in vapor pressure decreases the moisture content of the product:

$$\log \cdot p = -0.88 + \frac{3.8}{M}$$

As to the bulk density, the points in the trial plots are so scattered that for the moment no simple relation can be obtained with either surface tension, vapor pressure, heat of vaporization of the pure solvent, or the viscosity of the feed; it might be a complicated function of all these properties. Meanwhile, in the runs where 5% of a solvent was added, it seemed that there was no correlation between the bulk density and moisture content of the final product.

To make a detailed study of the effect of adding organic solvents, methanol and acetone were successively chosen as the

TABLE 7

Variation of Viscosity and Density with Concentration at 18.3°C

% Santomerse	Density (g/cc.)	Viscosity (C.P.)
5	1.030	1.362
10	1.060	1.684
15	1.092	1.870
20	1.121	2.110
25	1.164	2.925
30	1.190	4.150

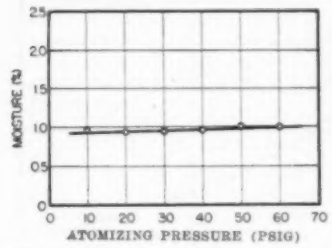


Fig. 8. Effect of atomizing pressure upon moisture content of dried product.

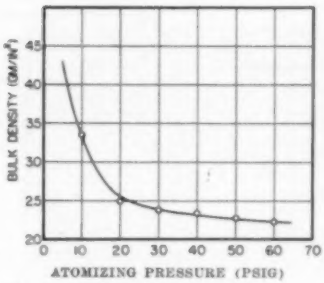


Fig. 9. Effect of atomizing pressure upon bulk density of dried product.

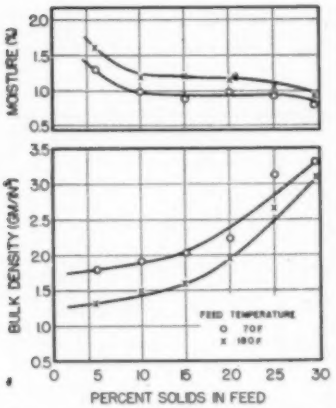


Fig. 10. Variation of bulk density and moisture content with feed concentration.

solvent added to a feed of 20% Santomerse No. 1. While maintaining constant all other operating conditions, the concentration of the solvent in the feed was varied to affect the change of vapor pressure of the feed. Experimental results were plotted in Figures 15-16. In Figure 15 the bulk densities of the spray-dried products were plotted versus vapor pressure of the feed of 20% Santomerse No. 1 with the addition of different amounts of methanol ranging from 10% to 50%. As the concentration of methanol increases, the vapor pressure of the feed increases, resulting in higher bulk densities. A similar plot for the case of adding acetone to the feed presented in Figure 16 indicates that the variation of the bulk density with the concentration of acetone in the feed passes through a point of minimum. At low concentration of acetone where the total vapor pressure of the mixture is low, an increase of vapor pressure results in a slight decrease in the bulk density until the minimum point beyond which an increase of concentration of acetone causes a sharp increase in the bulk density. This is in no way different from the case with methanol. From Table 4b it is seen that the bulk density of the product with 5% addition of methanol is 1.85 which is greater than the bulk density at higher concentrations below 50%, and if inserted in Figure 15 will indicate also the presence of a minimum for the curve resulting from the addition of methanol.

The rate of drying is directly proportional to the difference of partial pressure of water across a film surrounding a droplet; and inversely proportional to the diffusive resistance of the film. The addition of a volatile solvent in small amounts causes a slight decrease of the driving force represented by the difference of partial pressure of water vapor. However, an increase of total pressure inside the film was realized at some local points which were then broken to rupture the whole film. The rate of drying was increased upon a tremendous decrease of the diffusing resistance, giving rise to dryer products. As the specific gravity of Santomerse is lower than that of water, the dryer product has lower density. Under the same operating conditions which will probably give the same size and shape of the dried product, an increase of the concentration of the volatile solvent in this lower range causes a decrease in the bulk density. Beyond the concentration of the volatile solvent which gives the minimum bulk density, the decrease of partial pressure of water inside the film becomes larger, while the increase of total vapor pressure increases the tendency of the breaking film much less rapidly than the decrease of driving force for the diffusion of water. This will result in a slow rate of drying, and the final dried product carries higher percentage of moisture giving rise to the product of higher bulk density. Since the addition of acetone and methanol at the same concentration results in a product of different bulk density, it suggests that the other physical properties specific to each solvent or to the mixture of each solvent with the feed, are the other important factors in determining the bulk density as well as the moisture content of the spray-dried product. Figures 15 and 16 also present the relation between moisture content and the concentration of the solvent in the feed.

In the range of concentrations of the volatile solvents added to the feed (10% up), an increase of the concentration of a volatile solvent in the feed causes an increase in the total vapor pressure of the droplet and, hence, lower rate of

TABLE 5

Variation of Bulk Density and Moisture Content with the Addition of Methanol to the Feed

Entering Gas Temperature - 600°F
Feed Rate - 0.485 lbs/min.
Atomizing Pressure - 38 psig.
Feed - 20% aqueous solution of Santomerse #1

% Methanol (wt)	Bulk Density (gm/in³)	Vapor Pressure of Mixture (mm Hg. at 49.4°C)	% Moisture (dry basis)	Viscosity (c.p.)	Surface Tension dynes/cm.
5	1.8537	-	1.21	-	-
10	0.7415	110.1		3.05	29.0
15	0.6465	121.0	0.95	2.22	29.0
20	0.8210	132.6	1.32	2.69	29.0
25	0.9076	145.1	1.35	2.66	30.0
30	1.7855	155.0	1.56	2.68	30.5
35	1.6475	171.9	1.96	2.30	29.0
40	1.6968	186.0	2.09	2.24	31.0
45	1.8071	201.4	2.22	2.24	31.0
50	2.3986	217.8	2.37	2.22	31.0

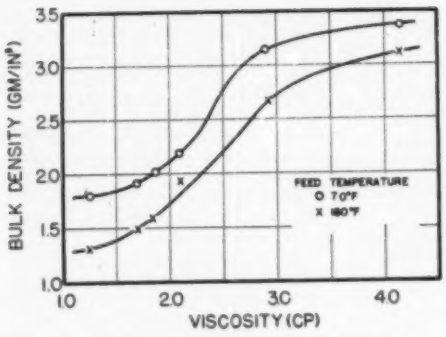


Fig. 11. Variation of bulk density with viscosity at various feed concentrations.

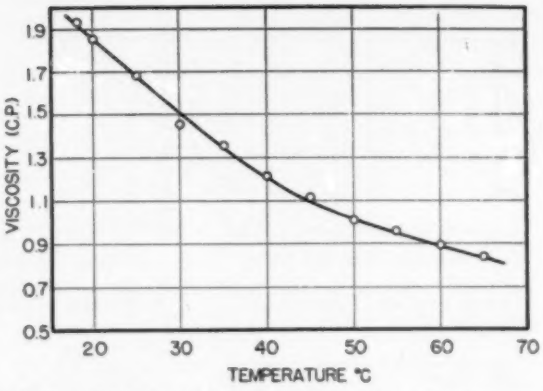


Fig. 12. Variation of viscosity of 20% solution with temperature.

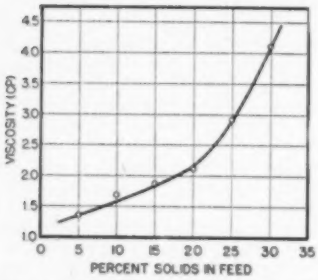


Fig. 13. Variation of feed viscosity with concentration.

drying which gives higher moisture content. It was noted that the moisture content of the spray-dried product with the addition of 5% of the volatile solvent to the feed was higher than that with higher concentration of the volatile solvent.

Similar to the bulk density, a minimum point is present also in the plot of the moisture content versus concentration of the volatile solvent. Viscosities and surface tension of the feed solution containing different amounts of methanol and acetone were measured. Since their variations with the concentration of each added volatile solvent were small, it was difficult to evaluate their relations with the properties of the spray-dried products. However, it was noted in Table 5 that the addition of a 5% different solvent to a solution of 20% Santomerse gave the viscosity of the latter ranging from 1.43 to 9 cp. Viscosity is therefore an important factor to account for the differences of bulk densities and moisture contents of the dried product from a feed with the addition of 5% different solvents.

Photomicrographs of Dried Product. As has been pointed out, use of two-fluid nozzles for atomization results in a shredded, irregular shape and size of the dried product. The structure of spray-dried particles is shown (Fig. 17) by magnified photomicrographs taken of the product obtained in the runs made using various feed concentrations.

The hollowness of the product may be noted, as well as the mixture of

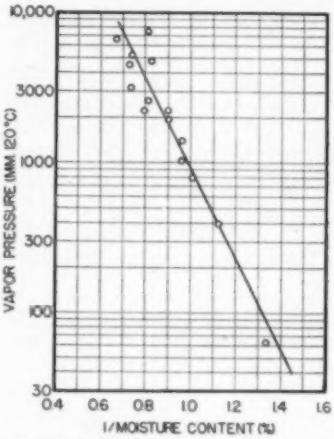


Fig. 14. Variation of moisture content with vapor pressure of organic solvents in feed.

spherical particles with irregular fragments and agglomerates. The proportion of hollow spheroids to exploded segments and incompletely formed particles,

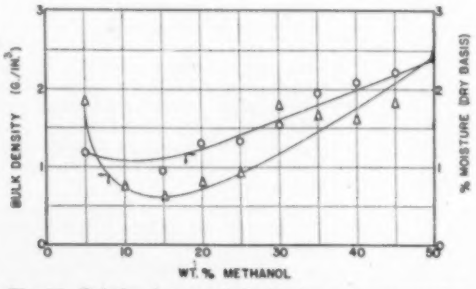


Fig. 15. Relation between bulk density and concentration of solvent in feed.

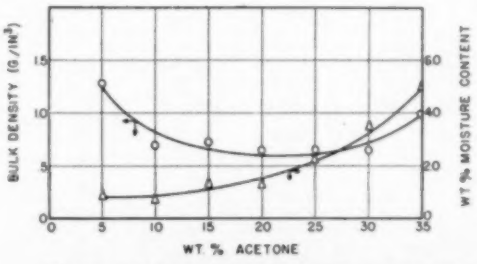


Fig. 16. Relation between bulk density and concentration of solvent in feed.

in conjunction with the degree of agglomeration of these various structures, determines the bulk density of the product. Fragments, able to be packed into a smaller volume, would have a high bulking weight.

It might be pointed out here that the spray dryer used in the present investigation was chosen because it is the only existing one available in the laboratory at Washington University. Two main difficulties in correlating the data from this small unit are:

1. With a fan situated underneath the desiccator, the dried product has been mechanically disintegrated into fine dust in passing through the fan on the way to the powder collecting system. It is difficult to get a granular product of larger size.
2. The size of the spray dryer may not be large enough to get the data which can be directly translated for the purpose of the design of a commercial unit. An additional disadvantage might be due to the use of the pressure-type nozzle, the mouth of which is widened after prolonged usage and requires a diminished pressure to keep from overloading the dryer. The rotating disk type has a uniformly fine spray formed independently of the quantity of the incoming solution. Particle size may be regulated by rotational speed.

Conclusions

The following engineering drying facts have been drawn from the experimental results obtained with the spray drying of Santomerse:

1. Both moisture content and bulk density decrease with an increase in the temperature of the drying gas, approaching more or less constant value at high temperature, 900° F. in this particular drying. Similar results were reported by Lamont (8) in his work on spraying of soap.
2. Bulk density decreases with an increase in atomizing pressure, whereas moisture content exhibits a slight increase. The relation between bulk density and atomizing pressure can be explained in the same way as Lewis's observation on atomization of water.
3. Bulk density rises with an increase in feed concentration, whereas moisture content exhibits a slight decrease. Bulk density decreases with an increase in feed temperature. The effect of temperature on bulk density and moisture content is less pronounced in a more concentrated solution. For a feed of 10%, a jump of feed temperature from 70 to 180° F. gives a decrease of bulk density of about 30%.
4. The addition of 5% organic solvent produces a change in bulk density and moisture content. It appears that no generalized correlation can be made between product characteristics of the spray-dried product and physical

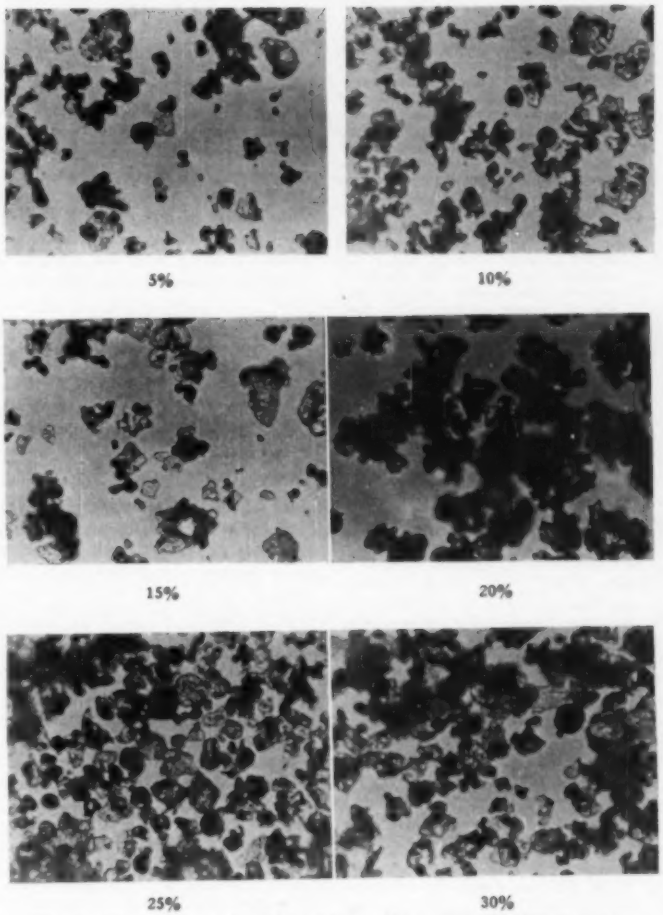


Fig. 17. Photomicrographs of the dried products magnified 300 diameters wt. % of Santomerse No. 1 in feed.

TABLE 9

Variation of Bulk Density, Moisture Content, with the Addition of Acetone to the feed

Entering gas temperature - 600°F
Feed Plate - 0.685 lbs/min.
Atomizing Pressure - 38 psig.
Feed - 20% aqueous solution of Santomerse #1

Wt.% Acetone	Bulk Density (gms/cu.in.)	% Moisture (Dry basis)	Vapor Pressure of Mixture (mm Hg. at 49.4°C)	Surface Tension dynes/cm	Viscosity (c.p.)
5	1.2769	0.867	-	-	-
10	.6973	0.72	106	29.0	2.82
15	.7280	1.35	118	29.4	2.51
20	.6480	1.30	129	29.7	2.45
25	.6510	2.26	142	30.0	2.30
30	.6475	3.5	157	29.9	2.11
35	.9857	5.0	172	28.9	2.00

properties of different pure organic solvents.

Methanol and acetone were successively chosen as the solvent added to a feed of 20% Santomerse. While maintaining all other operating conditions constant, the concentration of the organic solvent in the feed was varied to affect the change of vapor pressure of the feed. When bulk density and moisture content of the spray-dried product are plotted versus the concentration of the added organic solvent, a minimum point is noticed. Apparently, at least two opposing factors, presumably total pressure and partial pressure of water vapor, are present to account for the change of product characteristics after the addition of organic solvent to the feed. Since the addition of acetone and methanol at the same concentration effects products of different bulk density and moisture content of the dried product, it suggests that the other physical properties specific to each solvent or to the mixture of each solvent with the feed are also important factors in determining the product characteristics of the spray-dried product.

Acknowledgment

Grateful acknowledgment is made to Messrs. N. W. Seibel, W. R. Niehaus, F. H. Moulton and A. F. Aschoff, who assisted in obtaining the experimental data, and to Shell Chemical Corp., Carbide and Carbon Chemicals Corp., and Monsanto Chemical Co. who furnished the chemicals for these investigations.

Literature Cited

1. Banks, W. H., and Barkas, W. W., *Nature*, **150**, 341 (1946).
2. Boggs, M. M., and Fevold, R. L., *Ind. Eng. Chem.*, **38**, 1075 (1946).
3. Busche, R. M., Washington University Ch. E. Thesis (1949).
4. Fogler, B. B., and Kleinschmidt, R. V., *Ind. Eng. Chem.*, **30**, 1372 (1938).
5. Greene, J. W., Conrad, R. M., Olsen, A. L., and Wagener, C. E., *Chem. Eng. Progress*, **44**, 591 (1948).
6. Jones, A. B., U. S. Patent 2,249,960 (July, 1941).
7. Ladisch, R., *Chem. Ztg.*, **66**, 156 (1942).
8. Lamont, D. R., U. S. Patent 1,734,260 (November, 1929).
9. Lewis, H., *Ind. Chem.*, **10**, 439 (1939).
10. Livingston, R., "Physics Chemistry Experiments," New York, MacMillan Book Co., p. 112 (1948).
11. Monsanto Chemical Co., Application Date Bulletin No. P.118.
12. Reavell, J. A., *Trans. Am. Inst. Chem. Engrs.*, **6**, 124 (1928).
13. Topley, B., and Whytlaw-Gray, R., *Phil. Mag.*, **4**, 873 (1927).
14. Waite, R., *Chem. Ind.*, **59**, 659 (1940).

Discussion

Anonymous: We have worked on similar problems and found that moisture content can be controlled by controlling the air gas temperature and humidity and bulk density by controlling the gradient of the hot air temperature at the top of the dryer with smaller or larger droplets. We can produce the same density of material at a constant moisture over wider ranges. Have you evaluated, along with the changes in density, any other property which may have been changed along with the density and moisture?

Ju Chin Chu: We have not evaluated any other properties. We have another project on spray drying in which we are trying to work along the lines you mentioned so that we can find some way of controlling final moisture content and bulk density.

(Presented at Forty-second Annual Meeting, Pittsburgh, Pa.)

LETTER TO THE EDITOR

NOTATION FOR LARGE AND SMALL NUMBERS

Sir:

In the physical sciences, it has long been customary for the representation of very large or very small numbers to use a number of a magnitude between 1 and 10 multiplied by 10 to the appropriate power, as 6.06×10^{23}, or 1.84×10^{-5}. Not only is this notation cumbersome, but it also uses the awkward "x" to indicate multiplication and presents the opportunity for its confusion with "x" standing for an unknown quantity.

To overcome these objections, the writer proposes an exponential notation in which the power of ten by which the decimal number is to be multiplied is placed as a superscript over the decimal point, thus: $1^{-5}.84$. This notation is logical and concise. It may be as readily set up in type, employed for typewritten material, or written by hand, as the older notation with "x." The superscript may conveniently be regarded as the number of places the decimal point must be moved to the right if the exponent is positive, or to the left, if negative.

From its primary use for very large and very small numbers, the proposed notation may be conveniently extended to express all factors in a complex expression as decimal numbers between 1 and 10, with the appropriate exponent added. This furnishes a ready grasp of the order of magnitude of the quantity, and is particularly useful for computations with the slide rule, or with logarithms when only the mantissas are employed.

As an example in a common chemical engineering calculation, the Reynolds number for 4800 lb./hr. of water at 70° F. flowing in a 1.049-in.-diameter pipe is computed:

$$Re = \frac{DV\rho}{\mu}$$

D = diameter, ft.

V = velocity, ft./sec.

ρ = density, lb./cu.ft.

μ = viscosity, lb./ft.-sec.

$$Re = \frac{D}{12}\,\frac{V}{(62.30)(3600)(0.00600)}\,(62.30)\,\frac{\rho}{(0.9787)(0.000672)}\,\frac{1/\mu}{1}$$

In the proposed notation, this becomes:

$$Re = \frac{(1.049)(4^{3}.80)}{(1^{1}.2)(3^{3}.60)(6^{-3}.00)(9^{-1}.787)(6^{-4}.72)}$$

Ignoring the exponents, the magnitude of this quantity may be estimated by inspection to be about 5/1600, or 0.003. Summing exponents according to the usual rules, the approximation becomes $0^{7}.003$. The slide-rule figure is 2954, and it is apparent that this must be 0^{7} 002954, or 29,540.

Many similar applications immediately become apparent.

J. W. Clegg

Columbus, Ohio,

Nov. 21, 1950

ELUTRIATION OF FINES FROM FLUIDIZED SYSTEMS

MAX LEVA †

United States Bureau of Mines, Bruceton, Pennsylvania

The paper reports basic observations on the elutriation of fines from fluidized beds. The systems investigated, being of the simplest type, were essentially composed of one coarse and one fines component. Rates of elutriation could be expressed by way of the law governing first-order chemical reactions and typical rate constants could be calculated. It was shown that the rate constants are related to such variables as linear gas velocity, size of coarse and fines constituents, material density and bed height. The gas velocity was recognized as a system driving force and an analogy was suggested between a system of fines in coarse particles and solutions. The analogy was extended further and it appeared that concentration conditions in dense phase and dilute phase fluidized systems could be related by a modified form of Henry's law.

PARTICLE disintegration in fluidized systems is frequently an important factor that will influence the design and operation of a unit, as well as the economics of the process. While there might be many causes for disintegration, the more important are probably (1) development of internal stresses caused by thermal gradients in the material, (2) composition changes in the catalyst, for example, carbon deposition in certain hydrocarbon synthesis catalysts, and (3) mechanical attrition. While many materials such as synthetic ammonia and synthetic liquid fuels catalysts do not readily break down by themselves as a consequence of attrition, their mechanical strength is substantially decreased under reaction conditions, chiefly due to causes (1) and (2), and breakdown frequently occurs. For estimating the limiting mass velocity above which attrition rates will generally be high and prohibit prolonged operation of adsorbent beds, Ledoux (*9*) has suggested the following expression:

$$G = \sqrt{0.0167 \times \rho_s \times \rho_F \times D_p \times g}$$

Since in many catalytic reactions (such as the hydrocarbon synthesis) thermal effects and catalyst composition changes are probably more severe than in adsorbent beds, it is to be expected that, at the above mass velocity which is considerably above the minimum fluidization mass velocity, breakdown rates might well be substantial.

Regardless of whether catalyst losses may be permitted or not, fines must, in any case, be prevented from reaching the outside, and the installation of either filtering devices, necessitating increased operating pressures, or cyclones will be required. If it is desired to remove fines periodically from fluidized systems by intermittently blowing the system with a current of gas, an understanding of the laws of elutriation should be most desirable. In this paper, some fundamental relationships between operating variables and elutriation from fluidized systems are discussed. Although it is fully appreciated that the data and treatment suggested are far from complete some basic thoughts and observations are advanced which may in the future serve as a nucleus around which a more complete understanding of the kinetics and thermodynamics of elutriation phenomena may be built.

Experimental Work

General. A literature survey revealed that no data on the specific subject of elutriation from fluidized beds have been published. Considerable information, is, however, available on such related topics as pneumatic conveying (*2-5, 7-8*) and friction loss accompanying the flow of solid-gas suspensions in pipes (*5, 6, 12*). Perhaps the most pertinent related study was made by Roller (*11*), who undertook development of a method and design of a unit for air-analyzing powders. Essentially, a Roller air analyzer consists of a vertical cylindrical vessel which reduces gradually at the lower end and is joined by a semicircular tube that carries the charge to be analyzed. The air is carefully blown over the top of the powder at a rate corresponding closely to the terminal velocity of the particle size which it is desired to remove. As larger particles are to be conveyed, the air velocity is gradually increased, so as to correspond always more or less to the required terminal velocity as calculated from Stokes' law. The paper gives a good description of the difficulties encountered, such as attrition during the elutriation process, electrostatic forces, and cluster formation of particles.

Correlation of elutriation rates from industrial fluidized beds in terms of fluid velocity, viscosity, density, and other variables is complex, usually because the fraction of solids to be elutriated is in itself not a close cut, but possesses instead a characteristic size distribution. Since particles of the same density but of increasing diameter have increasing terminal velocities, it is evident that under the action of a given gas velocity the rate of removal of the small particles will be faster than that of the larger pieces. While this problem could be approached mathematically, in practice certain unknown effects—namely, the influence of the bed itself—must be accounted for. Since fluidized beds can be operated at fluid velocities greater than the terminal velocity of the smallest component

† Present address: Consulting chemical engineer, Pittsburgh, Pa.

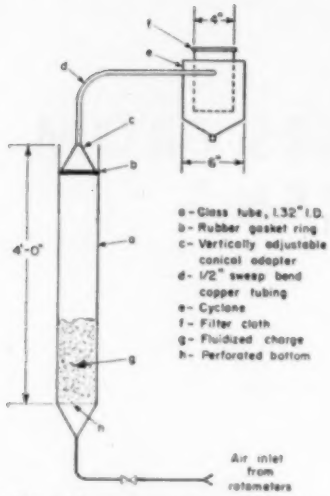


Fig. 1. Apparatus used for elutriation experiments.

in the bed with practically insignificant carry-over rates, it is apparent that the bed exerts a certain retaining influence on the solids.

Variables. This work describes results observed during elutriation of narrow cuts from fluidized systems. The scope of investigation as well as some original data are given in Table 1. In all, behavior of 13 different systems was examined. From an analogy which can be made between a mixture of fines in a parent bed of larger-diameter particles and a solution composed of solute and solvent, the fines will hereafter be referred to as solute and the parent bed (large-size component) as solvent. The diameter of the fines component will then be the "solute diameter" D_{st} and similarly D_{sv}, the "solvent diameter."

Table 1. Original and calculated data.

Experiment No.	Component diameter, Coarse (inch)	Component diameter, Fine (inch)	Initial percent, fines	Bed weight, grams	Linear gas velocity, (ft./sec.)	Elutriation velocity constant, (min.$^{-1}$)
a-1	0.00892	0.00382	20	200	0.805	0.00162
b-1	.00752	.00264	20	200	.855	.00065
2	.00752	.00264	20	200	1.12	.00142
c-1	.00752	.00202	20	200	0.70	.00083
2	.00752	.00202	20	150	.70	.00090
3	.00752	.00202	20	150	.90	.00142
4	.00752	.00202	20	150	1.08	.01000
5	.00752	.00202	20	150	1.08	.01370
d-1	.00752	.001595	20	150	0.725	.00600
e-1	.00752	.001595	20	300	.895	.0024
2	.00752	.001595	16.6	287	1.08	.00555
3	.00752	.001595	13.3	277	1.33	.0116
4	.00752	.001595	9.5	265	1.08	.0050
5	.00752	.001595	7.79	260	1.33	.0094
6	.00752	.001595	20	200	0.90	.0086
7	.00752	.001595	14.1	186	1.08	.0086
8	.00752	.001595	10.15	178	1.31	.0158
9	.00752	.001595	6.59	171	1.08	.00375
10	.00752	.001595	5.81	170	1.29	.0079
11	.00752	.001595	20	400	0.90	.0043
12	.00752	.001595	14.4	374	1.29	.0188
f-1	.00532	.001595	20	300	0.73	.00255
2	.00532	.001595	17.5	291	.90	.00433
3	.00532	.001595	13.9	279	1.08	.0120
4	.00532	.001595	9.08	264	1.29	.0850
g-1	.00532	.001595	20	300	0.73	.0028
2	.00532	.001595	16.3	287	.90	.00885
3	.00532	.001595	12.3	274	1.08	.0300
h-1	.00532	.001595	20	200	0.73	.0035
2	.00532	.001595	16.25	191	.90	.0059
3	.00532	.001595	11.50	181	1.08	.0131
i-1	.00892	.001595	20	300	0.73	.00232
2	.00892	.001595	18.3	284	.90	.00642
3	.00892	.001595	16.15	236	1.08	.00720
4	.00892	.001595	6.26	256	1.29	.0115
j-1	.00614	.001595	20	300	0.56	.00146
2	.00614	.001595	18.4	294	.73	.00165
3	.00614	.001595	15.6	288	.90	.00350
4	.00614	.001595	11.1	279	1.08	.00860
5	.00614	.001595	8.85	263	1.29	.0190
k-1	.00714	.001595	20	300	0.73	.00262
2	.00714	.004595	17.3	290	.91	.00301
3	.00714	.001595	14.9	282	1.07	.00715
4	.00714	.001595	10.35	268	1.29	.0158
l-1	.00752	.001595	20	300	0.91	.00537
2	.00752	.001595	13.7	278	1.09	.00835
3	.00752	.001595	9.93	266	1.30	.0215
4	.00752	.001595	5.63	254	1.09	-
m-1	.00752	.00202	20	300	0.90	.00105
2	.00752	.00202	19.35	296	1.09	.00153
3	.00752	.00202	17.75	292	1.30	.00538

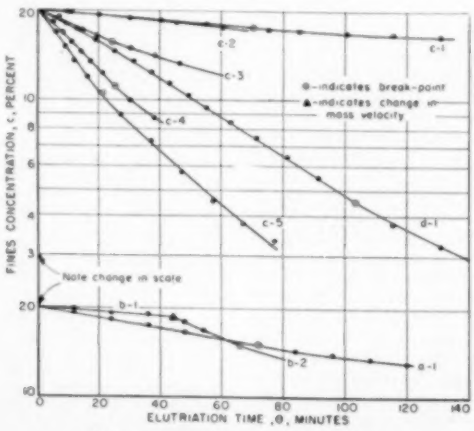


Fig. 2. Elutriation of sand mixtures.

The effect of the following variables upon elutriation rates was noted:

1. Gas velocity.
2. Solute diameter and concentration.
3. Solvent diameter and composition.
4. Specific gravity of solid phase.
5. Mixed density solids.
6. Column height.

Other effects, such as fluid viscosity, density, and tube diameter have been investigated in connection with more complex beds and these results will be presented in a later communication.

Unit and Operation. Figure 1 represents a sketch of the apparatus. The small cyclone on top of the unit worked satisfactorily, retaining essentially all the fine material. In preparing a sample, 80% of solvent was mixed in an outside container with 20% of solute (that had previously been elutriated to remove the finer constituents), and the charge was introduced into the vessel. A low rate of gas flow, sufficient for good fluidization without carry-over, was passed through for a few minutes to assure

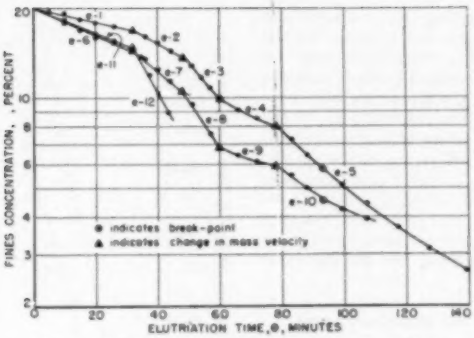


Fig. 3. Elutriation of iron Fischer-Tropsch catalyst mixtures.

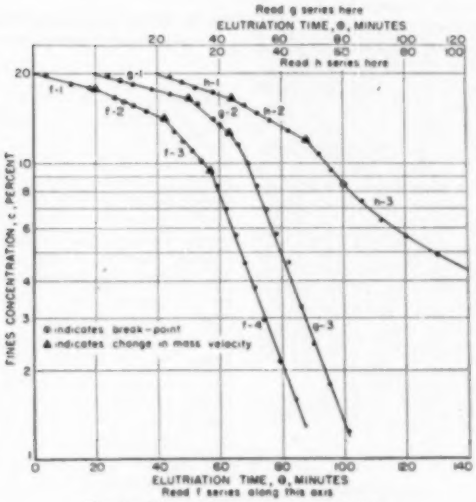

Read g series here
ELUTRIATION TIME, θ, MINUTES
Read h series here
FINES CONCENTRATION, c, PERCENT
● indicates break-point
▲ indicates change in mass velocity
ELUTRIATION TIME, θ, MINUTES
Read f series along this axis

Fig. 4. Elutriation of mixed materials.

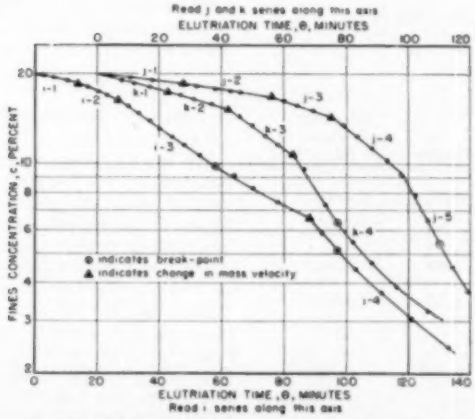

Read j and k series along this axis
ELUTRIATION TIME, θ, MINUTES
FINES CONCENTRATION, c, PERCENT
● indicates break-point
▲ indicates change in mass velocity
ELUTRIATION TIME, θ, MINUTES
Read i series along this axis

Fig. 5. Elutriation of iron Fischer-Tropsch catalyst mixtures.

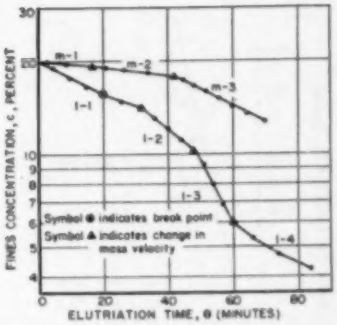

FINES CONCENTRATION, c, PERCENT
Symbol ● indicates break point
Symbol ▲ indicates change in mass velocity
ELUTRIATION TIME, θ (MINUTES)

Fig. 6. Elutriation of iron Fischer-Tropsch catalyst mixtures.

reasonable uniformity at the start, and the flow was then adjusted and held at a fixed rate for sufficient time to drive a small portion of the fines over. Carry-over usually amounted to 1 to 4 g. for any one period. It was important to work in small steps if differential rates were to be approached with this batch-type apparatus. The solids, recovered in the cyclone, were then weighed on the analytical balance and occasionally examined under the microscope for homogeneity. Several more runs were then performed at the same gas rate before the velocity was changed. All samples of fines were saved and weighed collectively at the end of a series of runs with any one system. The material balance was always better than 98% indicating insignificant losses. At the termination of experiments with any one series, sieve analyses of the solvent showed that no appreciable attrition had occurred.

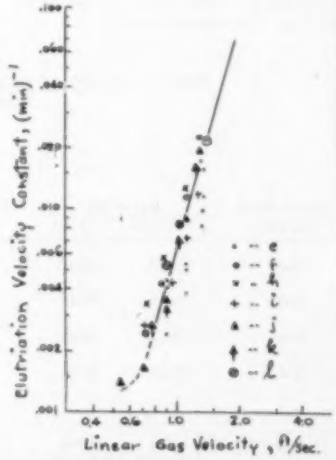


Fig. 7. Effect of solvent diameter upon elutriation velocity constant

(D_{si} = 0.001595 in.)

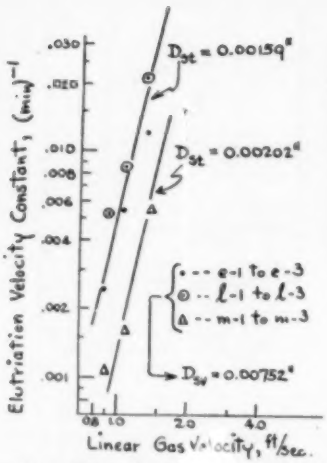


Fig. 8. Effect of solute diameter upon elutriation velocity constant.

At an early stage of the experiments, it appeared that electrostatic forces, so frequently observed with sands, affected the reproducibility of the results severely. The sand fines which left the bed adhered to the wall of the vessel, and, as the layer gradually built up in thickness, fell back under the influence of its own weight, thus destroying the value of the experiment. On some days, however, the electrostatic forces were negligible (perhaps due to air humidity), and several runs with sand could be performed satisfactorily. The electrostatic difficulties called for an early change-over to another solid. Iron Fischer-Tropsch catalyst particles were found satisfactory in this respect as they acquired no electrostatic charge at all and gave reproducible results.

Further orienting work indicated that the empty column height above the bed had a profound effect upon rates. A distinct concentration gradient extended upward from the top of the bed for a distance of approximately 6 in. When the adapter, leading to the cyclone, was lowered into this region of the apparatus, substantially higher elutriation rates were observed. Effect of height of the empty column was eliminated, however, if there were at least 12 in. between the top of the fluidizing bed and the outlet adapter.

Correlation and Comments

From an engineering point of view rates of elutriation and how they are related to the usual operating variables are of immediate importance. Therefore, as a preliminary step toward correlation, residual fines concentration in the beds have been shown in relation to time. Semilogarithmic coordinates have been chosen and all the data are thus recorded in Figures 2-6. Since, as a matter of choice, all the original beds contained 20% fines, all the curves are anchored at the same point. For definite concentration ranges, straight lines are obtained, for all practical purposes. However, beyond a certain concentration, referred to as "critical concentration," the linear relationship breaks down. The point itself beyond which the linear relationship ceases to hold has been termed "break-point," and all indications are that it is characteristic of the system to which it pertains.

The straight portion of the data suggests the equation:

$$c = c_o e^{-2.303kt} \qquad (1)$$

Equation (1) is readily recognized as the first-order reaction law. Constant k in Equation (1), termed the elutriation velocity constant, is therefore analogous to the kinetic constant in a first-order chemical reaction. This, being an interesting, though unexpected finding, should suggest rather definite steps toward correlation. Thus, just as the kinetic constant in a first-order chemical reaction system is dependent on its driving force, the temperature, so is (as will be shown later) the elutriation velocity constant a function of a driving force, which in this instance is the linear velocity of the gas. It should, however, be borne in mind that other system variables, such as fluid viscosity and density, material density, solvent and solute diameter, and probably particle shape will also affect the constant.

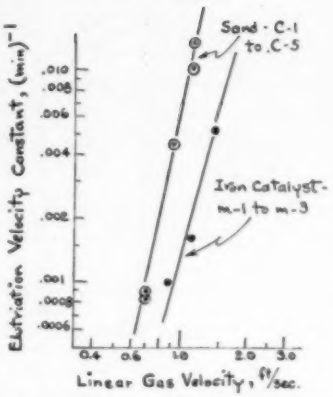


Fig. 9. Effect of material density upon elutriation velocity constant.

For the purpose of simple correlation elutriation velocity constants have been plotted for the various systems in relation to linear velocity (Figs. 7-10). Since on logarithmic coordinates all the data gave straight line plots of average slope 4.0, it follows that

$$k \propto u^{4.0} \qquad (2)$$

regardless of solvent-solute diameters and material density.

The effect of solvent diameter upon elutriation rates of iron catalyst particles 0.001595 in. in diameter is shown in Figure 7. A straight line of slope 4 may be placed through the upper portion of the data; the lower portion continues on a curve. This deviation from the straight line, not characteristic of the systems chosen, is due to the comparatively low fluid velocities employed. Velocities pertaining to the lower portion of the data are only little above terminal values. For investigation of these low velocity operating ranges, the

Table 2.- Effect of column height on elutriation velocity constant.

Experiment number	Material: Solvent	Material: Solute	Bed weight, (grams)	u, ft./sec.	Velocity constant k (min.$^{-1}$)
c-1	Sand	Sand	200	0.70	0.00083
c-2	Sand	Sand	150	.70	.00090
c-4	Sand	Sand	150	1.08	.01010
c-5	Sand	Sand	100	1.08	.01370
e-1	Iron catalyst	Iron catalyst	300	0.895	.0024
e-6	Iron catalyst	Iron catalyst	200	.90	.0046

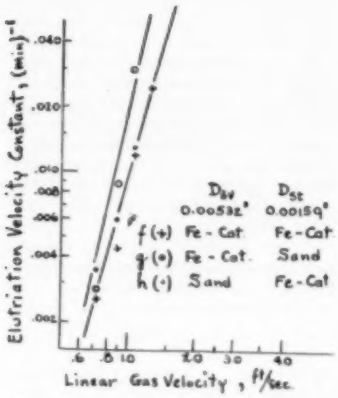


Fig. 10. Elutriation velocity constants for the heterogeneous systems.

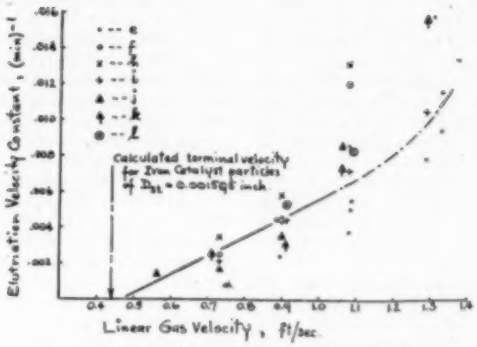

Calculated terminal velocity for Iron Catalyst particles of D_{st} = 0.00159 inch
Elutriation Velocity Constant, (min)⁻¹
Linear Gas Velocity, ft/sec

Fig. 11. Data of Fig. 7 on Cartesian coordinates.

choice of logarithmic coordinates is unfortunate, as it is impossible thus to locate the onset of elutriation for which, at a fixed linear velocity, the elutriation velocity constant will be zero. The limiting linear velocity for incipient elutriation may, however, be approximated from extrapolation of the data as shown on the cartesian plot (Fig. 11), which suggests an average value of 0.482 ft./sec., only slightly above the terminal velocity, 0.44 ft./sec., calculated for air at atmospheric pressure and iron catalyst particles of $D_{st} = 0.001595$ in.

The points in Figure 7 are scattered without apparent orientation, despite the fact that some solvents were close cuts and others had a rather wide size distribution. One may conclude, therefore, that the large-size fraction has comparatively little effect upon elutriation rates.

The effect of solute diameter is apparent from examination of Figure 8. A decrease in D_{st} from 0.00202 to 0.001595 in. causes a fourfold increase in the velocity constant; the variation is considerably greater than the scatter shown in Figure 7, indicating that elutriation rates are significantly influenced by the size of the fines.

Figure 9 emphasizes the effect of density of the system. Thus a nearly fivefold elutriation rate decrease follows an approximate doubling (165 to 312 lb./cu.ft.) of the particle density.

Figure 10 shows velocity constants for heterogeneous systems, consisting of sand and iron catalyst. Particle sizes of solvent and solute are the same for the three systems and it is instructive to note that the points pertaining to systems which have the iron catalyst as fines are (with one exception) below those of the systems containing sand as solute. The latter give higher elutriation rates, thus giving qualitative support to the earlier results, observed in Figure 7, that the solvent has comparatively little effect upon elutriation rates.

The experiments seemed to indicate that bed depth has some influence upon elutriation rates. As appears from Table 2, velocity constants are smaller for greater bed heights. This could be explained possibly by assuming that a small concentration gradient is established in the fluidized column. With high beds, it might conceivably take longer than with short beds for a sufficient fines concentration to be built up at the top of the bed so that removal by the gas is possible. When the fines content has been reduced to a certain low value, the transportation of fines to the upper bed surface proceeds at a slower rate than that at which the fines could be re-

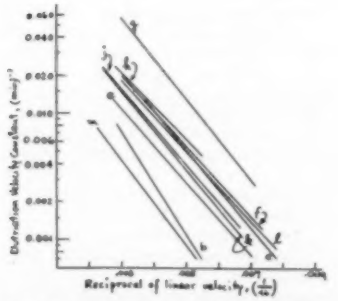


Fig. 12. Elutriation velocity constants in relation to reciprocal of linear air velocity.

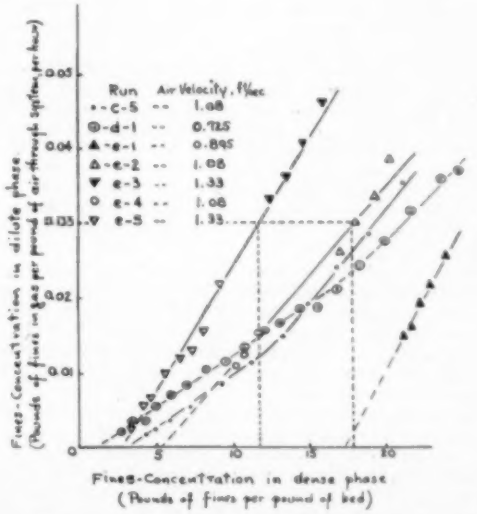

Run Air Velocity, ft/sec
c-5 -- 1.08
d-1 -- 0.725
e-1 -- 0.895
e-2 -- 1.08
e-3 -- 1.33
e-4 -- 1.08
e-5 -- 1.33
Fines-Concentration in dilute phase (Pounds of fines in gas per pound of air through system per hour)
Fines-Concentration in dense phase (Pounds of fines per pound of bed)

Fig. 13. Concentration data in dense and dilute phases.

moved by the gas stream. This, apparently, must occur near the critical concentration and is perhaps responsible for the appearance of the break-point. The exact location of the break-point probably depends upon many system variables such as rate of bed turnover, shape and character of the surface of the particles, density, and the ratio of solvent-solute diameter of the system.

When the logarithm of the kinetic constant of a first-order reaction is plotted against the reciprocal of the absolute temperature, straight lines of negative slope are obtained. Since the preceding analysis has indicated a certain analogy between the driving force in a first-order reaction system, *i.e.*, the temperature, and the gas velocity in a solid-solid system, composed of fines and coarser particles, a semilogarithmic data presentation for solid-solid systems suggests itself, with values of $1/u$ as the abscissa; such a plot is shown in Figure 12. The straight line correlation observed here lends additional support to the analogy between temperature and gas velocity.

Of particular interest is the group of lines composed of runs *e*, *f*, *h*, *j*, *k*, and *l*, representing the same points as have already been shown in Figures 7 and 11. For these data the solute diameter was constant at 0.001595 in., whereas the solvent diameters varied between 0.00752 and 0.00414 in. This being a significant variation, the comparative narrowness of the band (when compared with the total spread of all the data) indicates again that solvent size is not the important variable. The effect of solute size, however, is readily observed by comparing, for instance, run *m* (iron catalyst data) ($D_{ss} = 0.00202$ in.) with the band pertaining to 0.001595 in.

The analogy between solid-solid systems and solutions proposed earlier suggests existence of definite phase equilibria. Limiting the discussion now to homogeneous solid-solid systems, that is, systems where both solute and solvent consist of the same material, it may be postulated that a one-component system is of such a nature as to comprise essentially one singular size of particle. Systems composed of two, three, or four individual sizes will then be characterized as having two, three, or four components, respectively. Degrees of freedom associated with solutions are temperature, pressure, and concentration. When applied to solid-solid system, with no material volatility, only the property which is equivalent to temperature (*i.e.*, gas velocity) and concentration have to be considered. A solution will, if sufficient time is allowed, produce a vapor, and the two phases will reach a state of equilibrium that will depend on temperature, pressure, and concentration conditions. In a similar manner a system of fines in beds of coarser particles can, under the influence of a sufficient driving force, exhibit two distinct phases which are analogous to the *liquid* solution and its *vapor*. The two phases pertaining to the solid-solid system have long been known as the dense and dilute phase. For the two-component systems discussed here and the two distinct phases just mentioned, the phase rule would predict that there will be two degrees of freedom, which by necessity must be the gas velocity and the fines concentration in the bed. With both of these fixed, the concentration of solids in the dilute phase is also fixed, and, if sufficient time is allowed, eventually a state of equilibrium will be attained.

For ideal solutions of gases in liquids, Henry's law, $c_g = mc_l$, applies which states that the concentration of the gas in the vapor phase is proportional to its concentration in the liquid phase. In an attempt to interrelate the concentration of fines in the gas stream with the fines concentration in the bed, values of $y/w \propto c_g$ have been plotted versus c, the residual concentration. Data pertaining to systems which follow Henry's law will, when plotted on cartesian coordinates, yield straight lines that pass through the origin. Concentration data for some solid-solid systems, as shown in Figure 13, produce straight lines which do not, however, pass through the origin, the general equation being of the form

$$\frac{y}{w} \propto mc + a$$

where a is the residual fines content in the bed in equilibrium with zero fines concentration in the gas phase. This indicates that fluidized beds have a definite retentive capacity for fine solids. If the action were reversed—that is, if gas streams laden with a small amount of fines were passed through a fluidized system containing no fines—a certain filtering action of the bed should be experienced, removing part or all of the solids from the gas. This filtering action is small, however, and should be expected to depend perhaps on such system characteristics as mass velocity, concentration, and probably density, as well as particle size. It is of interest to point out in this connection that fluidized beds were found to be effective for removing finely divided mists of sulfuric acid, (*10*) a phenomenon that may be related to dust removal.

Examination of Figure 13 indicates the possible existence of states of equilibria between both phases. For the purpose of illustration, let it be desired to have a dilute phase characterized by a concentration of 0.03 lb. of solids/lb. of gas. This may be accomplished by having a series of conditions of gas velocity and fines concentrations in the dense phase, of which the two indicated in the figure ($c = 11.8$, $u = 1.33$; $c = 18.2$, $u = 1.08$) are merely an example. While certain phase relationships are thus clearly indicated, the data are not sufficient to construct a complete phase diagram.

Summary

Elutriation of a close cut of fines from fluidized beds proceeds for certain concentration ranges according to

$$c = c_o e^{-2.303 k \theta}$$

in which c and c_o are fines concentrations in the bed at times θ and zero, respectively, e is the base of the natural logarithms and k is the elutriation velocity constant.

The above kinetic equation, being the first-order reaction law suggested a parallelism between the elutriation velocity constant and the reaction velocity constant of a first-order chemical reaction. When the logarithms of the elutriation velocity constants were plotted versus the reciprocal of the gas velocities (the driving force) a series of straight lines of negative slope was obtained, analogous to plots of the logarithm of velocity constants versus the reciprocal of temperature.

The elutriation velocity constant is only slightly dependent on composition and composite size of the large component in the bed; it increases rapidly, however, as the fines decrease in diameter. Likewise, k increases rapidly with decreasing density of the fines. For the range of experiments investigated, the velocity constant varies with the gas velocity according to:

$$k \propto u^{4.0}$$

Below a certain fines concentration, referred to as the critical concentration, the simple relationship referred to in this paper between concentration and elutriation time breaks down. The point at which the equation becomes invalid was termed the break-point of the system. Below the break-point concentration, changes with time occur slower than when above the critical concentration. No correlation between break-point and system characteristics could be proposed; it is believed, however, that at the break-point the rate of turnover of the bed becomes a major factor.

An analogy between a system of closely screened fines in a bed of large particles on one hand and solutions of gases in liquids on the other indicated that a modification of Henry's law applies to the solid-solid system. Whereas

in a gas-liquid system zero concentration in the liquid corresponds to zero partial pressure of the component in the gas phase, in a solid-solid system a small but finite fines concentration seems to be in equilibrium with zero concentration of fines in the gas stream. This indicated that fluidized systems have a certain retentive or filtering effect upon fines carried along in gas streams. The data were not sufficient, however, to show how this property of fluidized beds depends upon system characteristics. An effect of bed height was observed which was believed to involve turnover characteristics and concentration gradients through the column.

Acknowledgment

Appreciation is expressed to Milton Grummer for his assistance in securing and calculating the data, to Murray Weintraub for numerous constructive suggestions, and R. C. Grass for review of the manuscript.

Notation

L = length

M = mass

θ = time—except as stated otherwise, units are in the foot, pound, hour system

a = residual fines content in bed (%)

c = fines concentration at time θ (%)

c_o = fines concentration at zero time (%)

c_g = concentration in gas stream (%)

cl = gas concentration in liquid (Henry's law) (%)

e = base of natural logarithms (no dimension)

g = conversion factor (gravitational constant) $L\theta^{-2}$

k = elutriation velocity constant (θ^{-1})

y = rate of elutriation from fluidized beds ($M\theta^{-1}$)

m = Henry's law constant

u = linear gas velocity (based on open tower) ($L\theta^{-1}$)

w = volumetric air flow rate through system ($L^3\theta^{-1}$)

D_p = particle diameter (L)

D_{sv} = diameter of large fraction (solvent) (L)

D_{si} = diameter of fines (solute) (L)

G = air mass velocity ($ML^{-2}\theta^{-1}$)

ρ_F = fluid density (ML^{-3})

ρ_s = solids density (ML^{-3})

θ = time (θ)

Literature Cited

1. Burke, S. P., and Plummer, W. B., *Ind. Eng. Chem.*, **20**, 1200 (1928).
2. Cramp, W., *Chemistry & Industry*, **44**, 207-*B* (1925).
3. Cramp, W., and Priestly, J. F., *Engineer*, **137**, 34 (1924).
4. Cramp, W., and Priestly, J. F., *J. Soc. Arts*, **69**, 283 (1924).
5. Gasterstadt, H., *V.D.I. Forschungsarb*, No. 265 (1924).
6. Hariu, O. H., and Molstad, M. C., *Ind. Eng. Chem.*, **41**, 1148 (1949).
7. Hudson, W. G., *Chem. Met. Eng.*, **51**, 147 (1944).
8. Jennings, M., *Engineering*, **150**, 361 (1940).
9. Ledoux, E., *Chem. Eng.*, **3**, 118 (1948).
10. Meissner, H. P., Mickley, H. S., *Ind. Eng. Chem.*, **41**, 1238 (1949).
11. Roller, P. S., *U. S. Bur. Mines Tech. Papers* 490 (1931).
12. Vogt, B. G., and White, R. R., *Ind. Eng. Chem.*, **40**, 1731 (1948).

Discussion

Anonymous: Did you run any experiment long enough to take 90% of your fines out? Looking at your curves, most data were 5%. What was the total per cent of fines taken out?

Max Leva: We attempted to elutriate as far as we believed necessary to establish any trends. In some cases up to 95% of the total fines were removed.

Anonymous: The main point I had in mind—does that straight line relationship hold for say 98% of the total?

Max Leva: For some systems it may, for others it may not. Just where the break-point will occur we cannot predict at present. The break-point location should primarily depend on the gas velocity and the constituent sizes.

Anonymous: One of the conclusions you made was that the size of the particle in the majority of cases did not make much difference. As you get closer to the size of the fines, have you worked down in that region, and what happened there?

Max Leva: The size of the coarse constituent has apparently less effect on the elutriation rate than that of the fines. For all the systems investigated here the difference between the size of the fines and the coarse particles was always appreciable. To narrow this range down substantially would require more refined methods of investigation than were used. Just what might be expected for very narrow ranges cannot be predicted without further experimental work.

A. B. Newman (College of City of New York, N. Y.): Elutriation is one of the operations that we don't hear about often. Could you give a definition of elutriation?

Max Leva: Elutriation is the process of separating a mixture of finely divided solids into individual components with the aid of a fluid current.

C. R. Bartels (E. R. Squibb & Sons, New Brunswick, N. J.): In your work did you ever allow a bed to come to rest and start it again to see if that affected the elutriation rate?

Max Leva: This point was not investigated as such, but while adjusting flows the beds had an opportunity to settle and no effect seemed apparent.

F. J. Smith (Pan American Petroleum & Transport Co., New York): You reached the conclusion that as you raised the catalyst level there was not much effect of the heighth of the disengaging space on the concentration of fines in the overhead stream from your experimental reactor until a well-defined minimum distance was reached. Did you form any generalized conclusions as to how to express that point in terms of diameter or height of the bed, superficial velocity, or other such factors?

Max Leva: The required disengaging space depends primarily on the gas velocity. For our conditions 12 to 18 inches was satisfactory for reproducible results. No attempt was made to correlate disengaging space in terms of operating variables.

F. J. Smith: Is it true that as you increased disengaging space when you passed a certain critical point, additional dropping of the catalyst level was without effect on fines carryover?

Max Leva: Yes, that is correct.

(*Presented at Forty-second Annual Meeting, Pittsburgh, Pa.*)

A GENERAL GRAPHICAL ANALYSIS OF CONTINUOUS REACTIONS IN SERIES OF AGITATED VESSELS

ROBERT W. JONES

Monsanto Chemical Company, Springfield, Massachusetts

CONTINUOUS flow has always been the obvious goal of engineers designing a plant for large-scale production. Unfortunately, in chemical processes, the initial laboratory work is done often intermittently, i.e., batchwise. Predicting results in a continuous flow system from such batchwise data is not easily done. MacMullin and Weber (*12, 13*) and Brothman with various associates (*2, 3*) have presented two different methods of attack to the problems involved in estimating the characteristics of the continuous system shown in Figure 1.

Both these authors' methods are generally applicable, but they require lengthy computations for reactions of unknown order. This paper presents a simple general graphical analysis of the problem, using nearly the same basic assumptions of MacMullin and Weber. It is hoped that this method for analyzing the potentialities of continuous flow through a series of agitated reaction vessels will be simple enough to encourage frequent consideration and quantitative analysis to the problem of converting batchwise processes to continuous processes in a series of agitated vessels.

Method. The following method is given first without proof so that its simplicity will be apparent.

Before this method can be used, the variation with time in a batchwise reactor of the quantity to be considered, i.e., per cent conversion, concentration, must be known. A mathematical expression is not necessary but a graph of the quantity, Q, versus time must be determined experimentally in a batch reactor.

From the graph of Q versus t (Fig. 2) obtain the slope, dQ/dt, as a function of Q (Fig. 3).

Through the point,

$$\left(\frac{dQ}{dt} = 0,\ Q = Q \text{ of feed}\right),$$

draw a straight line of slope $1/\theta_1$ where θ_1 is the nominal holding time in the first vessel—i.e., volume of vessel No. 1/rate of feed. (*See* Fig. 4.)

The point of intersection of this line with the plot of dQ/dt versus Q will then give Q_1, the value of the variable in the first vessel and in the effluent from this vessel.

Next through the point,

$$\left(\frac{dQ}{dt} = 0,\ Q = Q_1\right),$$

draw a straight line of slope $1/\theta_2$ where θ_2 is the nominal holding time of the second vessel.

Repeat the above process as often as desired. It should be noted that this method can just as easily be worked backwards starting with the value of Q existing in the last vessel.

Proof.

Assumptions: (The first two of these are the same as those made by MacMullin and Weber for every case except their Case VII in (*12*).

(1) That the composition in each vessel is uniform throughout, i.e., the feed is instantaneously dispersed homogeneously throughout the vessel. (This assumption was also made by Ham and Coe (*8*) in an earlier but less complete treatment of the subject.)

(2) That the rate of change of the variable considered will be the same in a vessel in a continuous flow system as in a batchwise vessel when the value of the variable is the same in both vessels. (*See Discussion*, Part B, for comments on the validity of this assumption.)

(3) That Q, the variable considered, is monotonic with respect to t, i.e., that $Q = f(t)$ has no maxima or minima. In still different language, that dQ/dt is a single-valued function with respect to Q. (This assumption is not essential for MacMullin and Weber's general Case VII in (*12*), but their other cases for reactions of 1, 2, 3, . . . or nth order involve functions which are monotonic.) (*See Discussion*, Part B, for an analysis of Case VII.)

(4) The variable considered must have additive properties with respect to volume increments, i.e., if several fractions of volume $V_1, V_2, \ldots V_n$ having values of the variable $Q_1, Q_2, \ldots Q_n$ are mixed together, the value of the variable Q of the mixture must be:

$$\overline{Q} = \frac{V_1Q_1 + V_2Q_2 + V_3Q_3 + \ldots V_nQ_n}{V_1 + V_2 + \ldots V_n}$$

In general, the only variables that will behave in this manner are those which are linear functions of the concentration of some material.

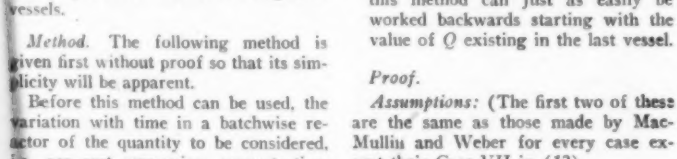


Fig. 1. A series of n kettles in continuous flow.

Argument:

Consider an infinitesimal portion of feed, dV, added to the first vessel of Figure 1, having a value of Q of Q_f. Then the value of Q in the first vessel will be (if there is a temporary halt in the overflow):

$$\frac{Q_f dV + V_1Q_1}{V_1 + dV} \quad \text{(Assumption (4))};$$

Then the infinitesimal change in Q will be:

$$dQ = Q_1 - \frac{Q_f dV + V_1 Q_1}{V_1 + dV}$$

$$= \left(\frac{Q_1 - Q_f}{V_1 + dV}\right) dV$$

or,

$$\frac{dQ}{dt} = \left(\frac{Q_1 - Q_f}{V_1 + dV}\right)\left(\frac{dV}{dt}\right);$$

now

$$\theta = \frac{V_1}{\frac{dV}{dt}},$$

and hence,

$$\frac{dQ}{dt} = \frac{Q_1 - Q_f}{\theta + dt}$$

If dt is made to approach zero, then

$$\frac{dQ}{dt} = \frac{Q_1 - Q_f}{\theta} \quad (1)$$

This dQ/dt is the necessary reaction velocity required to keep Q_1 constant which is the case after steady state conditions have been reached in the continuous process.

If this dQ/dt is the same as the reaction velocity in a batchwise system at equivalent values of Q (assumption (2)), then the two equations,

$$\left(\frac{dQ}{dt}\right)_{\text{batchwise or continuous}} = f(Q) \quad \text{(Fig. 3)}$$

$$\frac{dQ}{dt} = \frac{1}{\theta}(Q_1 - Q_f),$$

may be solved simultaneously to give the value of Q_1, if Q_f, θ, and $f(Q)$ are defined. Figure 4 is the graphical method of solving these two equations. The necessity for assumption (3) is to eliminate the possibility of two or more solutions to these equations.

Discussion.

A. *Comparison to Mathematics of MacMullin and Weber.* At first glance, this method may not appear to be equivalent to the mathematics of MacMullin and Weber, but since the assumptions made are identical, the results obtained are identical. Perhaps a consideration of only the first-order reactions will suffice to show this identity. For such reactions, MacMullin and Weber obtained the following expression for continuous processes:

$$D_n = 1 - \frac{1}{(1 + k\theta)^n} \quad (2)$$

where

k = reaction constant (units of time)$^{-1}$

θ = nominal retention time (same units of time as for k)

n = number of vessels

D_n = degree of completion of the reaction in the material in vessel number n

and, for batchwise first-order reactions,

$$D = 1 - e^{-kt} \quad (3)$$

or

$$\frac{dD}{dt} = k(1 - D) \quad (4)$$

Equation (4) is the necessary relation between dD/dt and D in order to use the method of this paper. The equation of the straight line, Equation (1), for the first vessel will be:

$$\frac{(dD)}{(dt)_1} = \frac{1}{\theta}(D_1 - D_f) \quad (5)$$

or

$$\frac{(dD)}{(dt)_1} = \frac{D_1}{\theta} \quad (6)$$

since $D_f = 0$.

Combining (4) and (6) to give the intersections of these two curves gives:

$$k(1 - D_1) = \frac{D_1}{\theta} \quad (7)$$

or

$$D_1 = \frac{k\theta}{1 + k\theta} \quad (8)$$

or

$$D_1 = 1 - \frac{1}{1 + k\theta} \quad (9)$$

The straight line for the second vessel will then be:

$$\frac{(dD)}{(dt)_2} = \frac{1}{\theta}(D_2 - D_1) \quad (10)$$

$$= \frac{1}{\theta}\left(D_2 - 1 + \frac{1}{1 + k\theta}\right) \quad (11)$$

Combining (4) and (11) will give:

$$D_2 = 1 - \frac{1}{(1 + k\theta)^2} \quad (12)$$

By repeating this process the deduction can be made that:

$$D_n = 1 - \frac{1}{(1 + k\theta)^n} \quad \text{(13) or (2)}$$

Similarly, the method of this paper will give results mathematically equivalent to any of the results of MacMullin and Weber except Case VII in (*12*).

(*See* Part B of this discussion.)

B. *Validity of Assumptions.* Application of this type of a continuous reactor has been discussed by several authors (*1, 4, 6, 7, 10, 11, 14-16*). Their discussion would indicate that assumption (1), instantaneous mixing, is valid for calculations provided the nominal holding time is reasonably large and that the agitation is good.

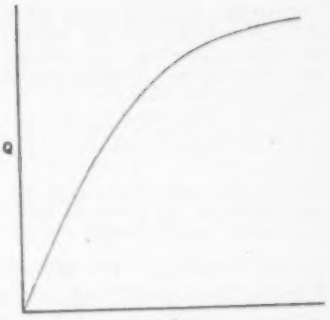


Fig. 2. Value of process variable vs. time in batchwise reactor.

Assumption (2), that the rate of change in a variable depends only on the value of the variable will not be valid for a large number of reactions. The reaction velocity of many complex reactions, particularly simultaneous reactions and those involving many side reactions, does not depend solely on the concentration of any one material. Hence, assumption (2) should be checked in the laboratory for all but the simplest types of reactions. Such a check usually need not involve a laboratory continuous reactor, but only the addition of fresh reactants to partially reacted material. If the rate of reaction is the same as that which would normally occur then assumption (2) may be considered valid.

The condition of assumption (3), that the variable considered must not have a maxima or minima, is met by nearly all reactions. For cases where assumption (3) is not true, assumption (2) normally will also be invalid.

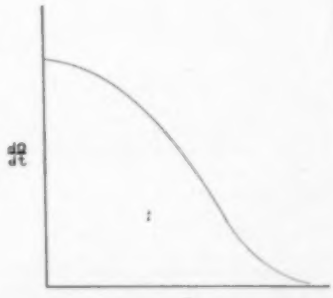


Fig. 3. Time rate of change of process variable vs. value of variable in batchwise reactor.

* Denbigh (*5*) obtained a similar relationship but applied it to calculating the order of batchwise reactions when using a continuous feed to a single agitated vessel.

MacMullin and Weber's Case VII in (*12*) involves a different assumption from assumption (*2*) presented here. They use the relation $Q = f(t)$, (Fig. 2), and the relation

$$y = 1 - e^{-\frac{t}{\theta}}\left[1 + \left(\frac{t}{\theta}\right) + \frac{1}{1\cdot 2}\left(\frac{t}{\theta}\right)^2 + \frac{1}{1\cdot 2\cdot 3}\left(\frac{t}{\theta}\right)^3 + \cdots \frac{1}{(n-1)!}\left(\frac{t}{\theta}\right)^{n-1}\right]$$

where y equals the proportion of material remaining in a system for time t. Now, using t as a parameter, they plot Q vs. y. The integral, $\int_n^1 Q dy$, will then be equal to the actual value of Q in the nth vessel only if Q is a function solely of time for each infinitesimal portion of the batch independent of the value of Q in neighboring portions. Also, this variation with time must be the same as in a batchwise reaction. Notice that the above also assumes that the properties and degree of reaction of neighboring portions will have no influence on the reaction. Whether the assumptions of this paper or those implied by the equations of MacMullin and Weber's Case VII (*See* above) are correct for a particular reaction must be determined by experiment.

Because of this different assumption, MacMullin and Weber's general method, Case VII, will give results that are different from the results obtained when their other methods or the method of this paper is used.

An exception to the above is found in first-order reactions. No difference will be found between the method of this paper or MacMullin and Weber's equation for first-order reactions and MacMullin and Weber's Case VII. This may be shown as follows:

Equation (13) of Part A of this discussion gives the value of:

$$D_n = 1 - \frac{1}{(1 + k\theta)^n}$$

Now as MacMullin and Weber did point out,

$$D_n = \int_0^1 D dy$$

where

$$D = 1 - e^{-kt}$$

and

$$y = 1 - e^{-\frac{t}{\theta}}\left[1 + \left(\frac{t}{\theta}\right) + \frac{1}{1\cdot 2}\left(\frac{t}{\theta}\right)^2 + \frac{1}{1\cdot 2\cdot 3}\left(\frac{t}{\theta}\right)^3 + \cdots \frac{1}{(n-1)!}\left(\frac{t}{\theta}\right)^{n-1}\right]$$

then

$$D_n = 1 - \frac{1}{(1 + k\theta)^n}$$

However, first- and zero-order reactions are the only ones for which the value of the integral $\int_0^1 D dy$, will be the same as the results of this paper's method or MacMullin and Weber's methods for reaction of a particular order.

It is believed from spot checks only that the method of this paper and MacMullin and Weber's special cases will give a value for the degree of completion of the reaction slightly lower than for MacMullin and Weber's general solution (Case VII) whenever the reaction order is higher than the first. This will give results that are slightly conservative and should make the method of this paper more desirable for design. Unfortunately, this belief could not be precisely proved as a general mathematical theorem.

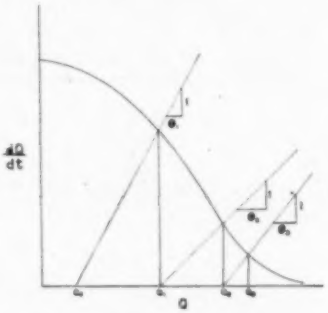


Fig. 4. Time rate of change of process variable vs. value of variable in batchwise reactor.

(Continuous system operating lines superimposed.)

Acknowledgments

Since this paper was first written, two previewers have made invaluable contributions which have led to important revisions.

Harold J. Kandiner, U. S. Bureau of Mines, by his comments established the need for assumption (4). He also is partly responsible for the realization that the method of this paper and that of MacMullin and Weber's Case VII are not the same. He is also responsible for pointing out that simultaneous reactions will normally not behave as is assumed by assumption (2).

R. B. MacMullin's comments pointed out the need for assumption (3).

Notation

Q = value of the observed variable in a continuous or batchwise process

$Q_{f,\,1,2,3\,\ldots\,n}$ = value of the variable in the feed or in the 1,2,3 . . . nth vessels

$\frac{dQ}{dt}$ = reaction velocity of Q in a batchwise or continuous system

$\theta_{1,2,3\,\ldots\,n}$ = nominal holding time in the 1,2,3 . . . nth vessel or $\frac{V\ 1,2,3\ \ldots\ n}{\text{rate of feed}}$

t = time in consistent units

k = reaction velocity constant in (consistent units of time)$^{-1}$

D = degree of completion of a batchwise reaction

$D_{1,2,3\,\ldots\,n}$ = degree of completion of a reaction in the feed or in the 1,2,3, . . . nth vessel

$\frac{(dD)}{(dt)}$ = rate of change of D with respect to time in a batchwise system

$\frac{(dD)}{(dt)}_{1,2,3\,\ldots\,n}$ = rate of change of D with respect to time in the 1,2,3 . . . nth vessel

Literature Cited

1. Bullock, H. L., *Chem. & Met. Eng.*, **52**, 116 (May, 1945).
2. Brothman, A., Weber, A. P., and Barish, E. Z., *Chem. & Met. Eng.*, **50**; Part I, 111 (July, 1943); Part II, 107 (August, 1943); Part III, 113 (September, 1943).
3. Brothman, A., Wollan, G. N., and Feldman, S. M., *Chem. & Met. Eng.*, **52**, 126 (May, 1945).
4. Crawford, R. M., *Chem. & Met. Eng.*, **52**, 106 (May, 1945).
5. Denbigh, K. S., *Trans. Faraday Soc.*, **40**, 352 (1944).
6. Dorr, J. V. N., *Chem. & Met. Eng.*, **31**, 463 (Sept., 1924).
7. Editorial Staff, *Chem. & Met. Eng.*, **52**, 110 (May, 1945).
8. Ham, A., and Coe, H. S., *Chem. & Met. Eng.*, **19**, 663 (1918).
9. Hulburt, H. M., *Ind. Eng. Chem.*, **36**, 1012 (1944).
10. Kandiner, H. J., *Chem. Eng. Progress*, **44**, 383 (1948).
11. Larian, M. G., *Chem. & Met. Eng.*, **52**, 111 (May, 1945).
12. MacMullin, R. B., and Weber, M., Jr., *Trans. Am. Inst. Chem. Engrs.*, **31**, 409 (1935).
13. MacMullin, R. B., and Weber, M., Jr., *Chem. & Met. Eng.*, **42**, 254 (May, 1935).
14. MacMullin, R. B., and Weber, M., Jr., *Chem. & Met. Eng.*, **52**, 101 (May, 1945).
15. Olsen, J. F., and Lyons, E. J., *Chem. & Met. Eng.*, **52**, 118 (May, 1948).
16. Shreve, R. N., *Chem. & Met. Eng.*, **52**, 103 (May, 1945).

PROBLEMS IN CHEMICAL ENGINEERING RESEARCH

E. R. GILLILAND

Massachusetts Institute of Technology, Cambridge, Massachusetts

. . . the 1950 recipient of the Professional Progress Award in Chemical Engineering wants the idea spread far and wide that the engineer's contributions are for the public weal and not for destruction . . . that engineers can not take a neutral position relative to science and engineering. . . .

THE chemical engineering profession in the United States has made great progress in the past 40 years. A great many of our members made outstanding contributions during World War II. I am still impressed at the almost universal success of the chemical plants built during the emergency; complicated plants that were designed on a little laboratory data plus a large amount of sound engineering judgment. This is not to be a eulogy of our profession; but it appears desirable to indicate that there are some good aspects to it before discussing some of its deficiencies.

One of our greatest weaknesses is in our chemical engineering research, particularly that portion of it carried out by our educational institutions. This program is of basic importance both to our educational programs and to industry. Observations of the research in various schools and consideration of the material presented in our technical journals lead me to the conclusion that our investigators are neglecting the fundamentals of the processes involved and are concentrating to too large a degree on empirical studies and performance tests. Today our field is based largely on the application of concepts developed by the physicists and the physical chemists. If we look at any one of our major unit operations, it is amazing how crude our fundamental concepts are and how little the chemical engineer has contributed to them.

Heat transmission is probably one of our most quantitative fields, but for the important case of heating or cooling of fluids we are still almost completely dependent upon empirical relationships which are undoubtedly unsatisfactory in many cases. Some progress has been made in the development of the analogies between heat and momentum transfer, employing concepts of films, turbulent cores, and buffer layers; concepts which are crude. Even in this case, the basic contributions have not been made by the chemical engineer. Turbulence is undoubtedly a phenomenon that increases progressively from the wall rather than by discrete jumps as implied in a film-core type of concept. Our research program should be able to develop a more fundamental approach to the problem.

While the situation in heat transfer is inadequate, our knowledge of mass transfer is in even less satisfactory condition. Mass transfer is one of the foundation stones of several of our major chemical engineering operations. It is of fundamental importance in the processes of absorption, distillation, extraction, adsorption, and catalysis. In the years we have been using and studying mass transfer, I do not believe we have made any real improvement in the fundamentals over those suggested by Maxwell, Fick and Reynolds. Maxwell developed a relationship which, empirically, applies reasonably well to molecular diffusion in ideal gases. However, such relationships are not particularly useful to the chemical engineer because the rate of transfer by molecular processes is so slow that, in general, other techniques must be employed to obtain satisfactory rates of transfer. Consider the case in which a pure liquid is evaporating into a turbulent gas stream. To simplify the problem, focus attention on the gas phase only. In so simple a case as the transfer of a single vapor component through a single gas, we do not know the proper driving force for the rate equation, i.e., to date no one has undertaken an adequate study to determine whether partial pressures, molal ratios, concentration per unit volume, or some other unit of concentration, is the proper driving force. As a result, our chemical engineering literature is full of empirical equations in which the investigators have assumed whatever driving force appealed to them. This has led to a great deal of confusion and complications. When the diffusing gas is dilute, most of the concentration units employed as driving forces can be readily related to each other and, from the empirical viewpoint, it makes little difference which is employed. However, if the concentration of the vapor is high, there would be large differences between the various transfer potentials and, even though it were not possible to elucidate completely the mechanism of mass transfer, it should be feasible to demonstrate which of the various concentration driving forces would be preferable for all concentration regions.

If the simultaneous transfer of more than one component through another gas is involved, the problem becomes more complex. In general, if the gases are dilute it is assumed that each of the gases is transferred essentially independently of the others present. On the basis of this picture, the mechanism of evaporation of mixed solvents has been developed and it has been concluded from the principles of mass transfer that the ratio in which the mixture evaporates should be a function not only of its vapor-liquid equilibrium, but that it should involve its relative mass-transfer properties and, therefore, in most cases, the relative rate of evaporation will not be the same as the relative rate of removal for a simple distillation process. However, some investigators, on the basis of their experimental data, have questioned this conclusion. If their data and their analysis of the problem are correct, it throws

EDWIN R. GILLILAND, professor of chemical engineering at Massachusetts Institute of Technology, and winner of the Professional Progress Award in Chemical Engineering for 1950, became an instructor at M.I.T. in 1934. Subsequently he became assistant professor, associate professor, full professor. Nor have his energies been devoted exclusively to the classroom—he served in the Office of the Rubber Director and with the National Defense Research Committee, has been in editor's chair, and has been joint author of technical books.

considerable doubt on some of our concepts. In most mass-transfer operations involved in chemical engineering, the process involves a transfer from one phase to another. While the knowledge of mass transfer in gases and vapors is almost negligible, it is an order of magnitude greater than that of the mass transfer in other cases, such as through liquid phases and through porous solids. We assume that in the transfer between phases equilibrium is attained at the interfaces. It is obvious that true equilibrium cannot be obtained at an interface for a process involving net mass transfer to or from the interface. It could be possible that the differences from equilibrium would be negligible. However, in some cases it is almost certain that the interface must be far from equilibrium, but our research programs have done little to resolve the problem.

In studying the over-all effect of the mass transfer through two phases, it has been customary to use the so-called two-film theory. This theory pictures an interface bounded on each side by relatively nonturbulent layers of fluid which are called the films and which constitute the main resistance to transfer. The effect of these films is assumed to be such that all the material being transferred has to pass through them in series, i.e., they are of such dimensions that they cannot offer any reservoir or mechanism for accumulation or depletion of the component to be transferred. On the basis of this picture, the additivity of the resistance of the two films is employed to obtain the resistance for the over-all process. While this picture has been applied by numerous investigators and authors to mass-transfer problems, it is difficult to find any of our major transfer operations that fulfill the requirements. In the case of bubbles passing through a liquid, it has been found that a major portion of all the transfer takes place during bubble formation. It is probable that the rapid transfer observed when the bubble is forming is due to the fact that new surface is being rapidly produced and that the major portion of the transfer is taking place before any condition equivalent to the film is encountered. In fact, probably a major portion of the interchange is due to accumulations or depletions in the surfaces adjacent to the interface. In the case of drops falling through another fluid, the experimental evidence indicates that the absorption is intimately related to the oscillation in the drops. These oscillations cause distortion of the drops and new surfaces are created periodically. In the case of packed towers, it is difficult to conceive of the postulated film in the liquid phase. The liquid adjacent to the gas is flowing at a considerable velocity and is probably just about as turbulent as any portion of the liquid. If there is any laminar-type film involved it is probably not at the interface with the vapor but next to the packing.

Professor Gilliland addressing the Columbus meeting.

There is undoubtedly resistance to mass transfer in both phases but instead of a two-film concept we should probably consider a two-phase picture. The apparent success of the two-film theory in some cases is probably due to the fact that a number of the important variables would occur in a similar manner in either process. However, there are fundamental differences between the two theories and the two-phase concept should furnish a sounder basis.

The packed tower is a good example of how far the chemical engineer has gone in attempting to apply empiricism. The results to date are far from successful and a brief review of the fundamental processes involved leads me to the conclusion that the techniques that have been employed are not likely to furnish satisfactory relationships. The application of the two-film concept to the packed tower is probably one of the minor errors. The rate equations that have been proposed to deal with this type of unit have assumed that the operation is a uniform and regular process. Differential equations have been applied to a given cross section assuming that the liquid and the gas have some definite compositions. Actually, the passage of the liquid and gas through the packed tower is nonuniform; both fluids have wide ranges of residence-time, wide ranges of velocity, and wide ranges of distribution. It is probable that at any given cross section there are variations in composition in each phase almost equal to the over-all composition change for the unit. These variations when applied on an average basis probably have little chance of being able to correlate or reproduce the actual process. The packed tower is undoubtedly a complicated operation and it is not going to yield to any simple analysis. In view of the complications involved none of the design techniques so far proposed appears to be satisfactory. The method of using a height equivalent to a plate does not duplicate the phenomena involved. On the other hand, the other bases that have been employed, such as differential equations or the height of a transfer unit, are probably not much closer to the truth than is the plate concept.

It is unfortunate that today it is not possible to evaluate packed-tower operations or to predict their performance with any degree of accuracy. However, more unfortunate is the number of man-hours that chemical engineering thesis students have spent in operating packed towers and in attempting to analyze results on unsound bases. It has been a waste of manpower that could have been better utilized to study more fundamental problems of mass transfer. We need a philosophy of no more theses on packed towers—a philosophy that might lead to studies of the mechanism of mass transfer under simple conditions that offer the possibility of reasonable interpretations. Performance data on packed towers will be required by industry but they should obtain such information where it is needed for a specific operation, and the universities should concentrate their programs on attempts to clarify the fundamental mechanisms involved. The chemical engineers in the universities are neglecting their obligations in this respect.

In interphase transfer, equilibrium data are usually required and such data are also a basic necessity in many of our other operations. Our knowledge of vapor-liquid equilibrium is largely that obtained from physical chemists, although the chemical engineer has made a major contribution in the effect of deviations from the ideal gas laws on equilibrium conditions. A more important contribution would be the development of a practical theory of nonideal solutions. Most of the crude attempts that we make at predicting or correlating vapor-liquid equilibria for such solutions are based on the work of Margules and van Laar. Both these developments date back almost 50 years. It is my opinion that most present-day physical chemists do not have their main interest in the theory of solutions but have turned their attention to other fields, and, for that reason, the probability of obtaining improved relationships from them does not appear to be too great. It is necessary for the chemical engineer to take over the functions of the physical chemists in this field if

(*Continued on page* 19)

RESORT MEETING IN MARCH

THE Greenbrier, White Sulphur Springs, W. Va., will be the site of the next meeting of the A.I.Ch.E., March 11-14, 1951. This will be the second visit of the Institute to the Greenbrier, having met there previously in 1938. The Charleston, W. Va. Section will serve as sponsors for this meeting which will follow, in plan, the successful and satisfactory "resort meetings" of the Institute. The Program Committee of A.I.Ch.E. has been encouraged by members and officers to develop single-theme technical meetings located at famous spas and resorts, usually at off-seasons. As a rule such conventions are less expensive than city-hotel meetings, and they give to chemical engineers better opportunities for staging successful technical programs.

Main front entrance of The Greenbrier in White Sulphur Springs, W. Va., showing the newly created porte-cochere.

Historical Territory

"White Sulphur Springs," for years a legend among many generations which have enjoyed the benefits of its restful waters and the exhilaration of its fine climate, has a colorful and historic past.

Actually, the Indians and their medicine men knew the "magic waters" of this locality long before the coming of the White Man. There was a famous salt lick in the marsh below the spring, with buffalo, elk and deer crowding around it. Here an Indian could both hunt and soothe his lumbago—his idea of a happy hunting ground.

The first white person to derive benefit from the waters of the spring, was a Mrs. Anderson who, old and ailing with rheumatism, was carried on a stretcher to this spot in 1778. In a humble wooden tub hollowed out of a tree, placed over hot stones to heat the water, the first sulfur bath was taken. Such were the results that the rumors of Mrs. Anderson's "cure" in the wooden tub soon brought others. Tents were pitched around the spring, then a cluster of log cabins, many of which were rented out to visitors by a James Calwell.

Because of the increasing demand for accommodations, Mr. Calwell began building the Cottage Rows. It was these Rows which sprang up that gave the property the character which it never has lost and which, under the names of Paradise Row, Georgia Row, Alabama Row and Baltimore Row began early to stretch a cordon around the little hill where the spring welled up.

By 1850, the popularity of White Sulphur Springs induced Mr. Calwell to start plans for a hotel. It was to be known as "The Old White" . . . calculated to become the finest in the land. Unfortunately for Mr. Calwell, he died before his splendid dream could be realized and it was under the supervision of his son that The Old White was completed in 1858. And, in the era which ensued, there appeared ample proof of the older Calwell's foresight as White Sulphur Springs flourished into a spa as popular and as fashionable as any in Europe. To it flocked the great and illustrious of their time. It became the summer White House of Presidents Van Buren, Tyler and Fillmore and its old registers contain the names of nine other of the nation's leaders. For several years, General Robert E. Lee made his home in the corner cottage of Baltimore Row. Shortly after the turn of the century, what had been a famous watering place became, as well, a social playground of world renown. Accordingly, in 1910, when the Chesapeake and Ohio Railroad acquired the property, work on the original and then ultramodern Greenbrier was begun. On the completion of The Greenbrier in 1913, all but one wing of The Old White was razed. That which remained was utilized as an annex.

In 1930-31 the original Greenbrier was rebuilt and more than doubled in size, the old cottages were restored, sports facilities rebuilt and modernized.

In 1942, after having served as an internment center for enemy diplomats, the entire property was sold to the United States Army for use as a general hospital. It served in that capacity until late 1946 when the resort was repurchased by the Chesapeake and Ohio Railroad and subjected to what is probably the largest rehabilitation project of its kind ever undertaken in this country, opening officially in April, 1948.

Unique Meeting

The subject of the entire A.I.Ch.E. meeting will be "Relationship between Pilot-Scale and Commercial Chemical Engineering Equipment." The technical program is under the direction of Walter E. Lobo, M. W. Kellogg Co., who is also planning to make available preprints of all papers. There will be a cocktail party Sunday evening, and general sessions Monday, Tuesday, and Wednesday mornings and afternoons. Details of the program will be given in "C.E.P." next month along with more news on the preprint plan of the Program Committee.

Plant Trips

Plant trips have been arranged to visit Industrial Rayon and West Virginia Pulp and Paper plants at nearby Covington, Va. The Industrial Rayon Co. produces continuous filament by the viscose process and employs 1200 to 1500 people. The West Virginia Pulp

From top to bottom: John McClain, Monsanto Chemical Co., committee on plant visits; Joe Cresce, Monsanto Chemical Co., committee on registration; Walt Canham, Monsanto Chemical Co., entertainment committee, and James Roe, Monsanto Chemical Co., chairman, committee on plant visits.

Left: Honorary chairman, W. S. Brackett, vice-president, Carbide and Carbon chemicals division, Union Carbide and Carbon Corp., and right: chairman, general committee, Thompson Chandler, Carbide and Carbon chemicals division, Union Carbide and Carbon Corp.

and Paper Co. produces sulfite paper, has a large mill and recovery unit, and employs about 2000 employees.

The technical portion of the meeting will be entirely different from any previous resort meeting. The plan is to develop and exchange ideas through informal discussions. Since this meeting is being held at a resort hotel, away from any large city, the expenses for those attending should be less.

For the sports enthusiasts there are three golf courses, tennis courts, saddle horses and an excellent all-weather swimming pool. There will be a golf tournament for the men with prizes for the winners. No formal golf tournament will be organized for the ladies.

Three trips have been scheduled for the ladies—a visit to the Homestead at Hot Springs, Va., a tour of the various points of interest in and around Lewisburg, W. Va., and the ladies have been invited to be guests at a tea at Morlunda, the farm of Oscar Nelson, president of the United Carbon Corp.

The Committee on Arrangements for this meeting includes Thompson Chandler of Carbide, chairman; F. A. Ott, Du Pont, vice-chairman; J. H. Howell, Carbide, treasurer; Roland Voorhees, Carbide, secretary; and A. B. Stiles, Du Pont, chairman of the local section for 1950-51. W. S. Brackett, vice-president, Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corp., a resident of Charleston and one of the founders of the local section, will be honorary chairman for the meeting.

Travel

How to reach the new Greenbrier, White Sulphur Springs, W. Va.:

By Train: The new Greenbrier, overnight from three quarters of the nation's largest cities, is on the main line of the Chesapeake and Ohio Railroad.

By Motor: The Midland Trail, U. S. Route 60, passes the gates of the Greenbrier.

By Plane: The Greenbrier Airport, a CAA Class 2 field, is only one mile from the hotel. Its unobstructed approaches, its 3500-ft. concrete runway and its full servicing and storage facilities make it an outstanding field for most types of aircraft. Charter service, operated by a certificated airline pilot, is available to and from any point, as well as to and from three nearby terminals served by leading commercial airlines.

From left to right: R. W. Timmerman, Westvaco chemical division, Food Machinery and Chemicals Corp.; W. V. V. Bacon, Westvaco chemical division, Food Machinery and Chemicals Corp., chairman; R. H. Westfall, Westvaco chemicals division, Food Machinery and Chemicals Corp.; J. R. Kernan, Carbide and Carbon chemicals division, Union Carbide and Carbon Corp., chairman, program and papers committee; H. M. West, Carbide and Carbon chemicals division, Union Carbide and Carbon Corp., member, program and papers committee.

COLUMBUS MEETING FEATURES AWARDS, COMMITTEE MEETINGS, NEW PUBLICATION

IF any characteristic can be given to the annual meeting at Columbus, Dec. 3-5, it would be that of quiet determination. The 1400 chemical engineers who attended were placing their attention on the requirements of a recently increased industrial mobilization program. The status of engineers under Selective Service, the effect of the draft on students and college enrollments, and the substantial progress reports of Institute committees were the chief topics of interest, outside of the technical program.

Above are shown J. A. Gerster, professor of chemical engineering, University of Delaware, one of the speakers at the technical sessions, and winner of an award for the presentation of his paper. The second is the newly elected President, Dr. Thomas H. Chilton of DuPont, as he appeared on Sunday's panel on the accrediting of graduate programs. The third is C. R. DeLong, Treasurer of A.I.Ch.E. and consultant of New York City, as he delivered his annual statement on the on the financial condition of the Institute. The fourth is O. A. Hougen of the University of Wisconsin delivering the Second Institute Lecture.

President W. L. McCabe made the award presentations at the annual banquet at Columbus. The top picture shows Prof. E. R. Gilliland of M.I.T. receiving a certificate signifying his winning the Professional Progress Award. Middle picture shows Prof. B. F. Dodge of Yale University, winner of the Walker Award. The bottom picture shows F. M. Tiller of Vanderbilt University who won the Junior Award. In the left background in the bottom picture is Prof. T. K. Sherwood of M.I.T., who is chairman of the Awards Committee and who presented the winners to the audience.

The meeting featured one of the quietest and shortest annual business meetings on record. Most of the important discussion of Institute progress took place in committee meetings. The annual business meeting, over which President Warren L. McCabe presided, heard brief reports from the Secretary, S. L. Tyler; from the Chairman of the Admissions Committee, R. P. Kite of The Dorr Co.; Chairman of the Membership Committee, C. G. Kirkbride of the Houdry Process Corp.; and Chairman of the Accrediting Committee, G. G. Brown of the University of Michigan. The Chairman of the Teller's Committee, L. P. Scoville of the Jefferson Chemical Co. reported on the results of the members mail ballot on the election of officers. Mr. Scoville stated that 1935 ballots were cast; President-elect Thomas H. Chilton received 1858 votes, Vice-President William I. Burt received 703 votes, Treasurer Carl R. DeLong, 1851 votes, Secretary Stephen L. Tyler, 1848 votes. Directors elected for a three-year term beginning January, 1951, were Charles R. Nelson who received 1054 votes, Earl P. Stevenson, 861 votes, R. C. Gunness, 777 votes, R. Paul Kite, 729 votes. Other candidates received the following votes: Vice-President, William T. Nichols, 641, Melvin C. Molstad, 526; Directors, Donald L. Katz, 688, William T. Dixon, 640, Cecil L. Brown, 538, Robert L. Sibley, 497, Reuben S. Tour, 461, Curry E. Ford, 430, Richard D. Hoak, 361, and Ralph H. Price, 331.

Mr. Tyler revealed in his report that the membership had increased approximately 7% during the year from a total of 9,711 to 10,386. He also said that seven new local sections had been created during the past year.

George Granger Brown, as Chairman of the Accrediting Committee, reported a re-examination of all accredited school curricula in cooperation with Engineers' Joint Council. He said that 34 schools had requested inspection during the year. This was done with the result that 13 were fully accredited, 16 were provisionally accredited, and 4 were denied accrediting. Dr. Brown also said that the Committee on Accrediting was considering, upon the instructions of Council, the accreditation of postgraduate work in chemical engineering. An open forum on the subject had been held the day before in Columbus as part of the Sunday afternoon program. Dr. Brown reported that E. C. P. D. was also considering the same type of accrediting in graduate work, but that it had been agreed that no graduate accreditation would be done in chemical engineering without the consent and cooperation of the Institute.

C. G. Kirkbride, Chairman of the Membership Committee, stated that the

Three members of the Public Relations Committee of the Columbus meeting are shown left above. They are R. B. Filbert, Jr.; C. E. Dryden, of Battelle Memorial Institute and chairman of the Columbus Public Relations Committee; and George F. Sachsel, of Battelle Memorial Institute. Above right are: F. C. Croxton, of Battelle Memorial Institute, co-chairman of the Columbus meeting, and J. Bradbury of Battelle Memorial Institute and chairman of the Registration Committee.

purposes of the membership drive were to attract to Institute membership those qualified for membership but who had not seen fit to apply. The purpose of the drive, he said, was to increase membership in the Institute in order to increase services rendered to the profession. He also predicted that the effects of the drive will begin to be felt in increased numbers during 1951.

New Publication

One of the important results of the committee meetings was the final whipping into shape of a plan to publish separate volumes of technical material by the Institute. Long considered a necessity, the Publication Committee in an open meeting, worked out final details including the name "Chemical Engineering Progress Symposium Series." The Institute intends to publish other volumes also, to be known as the "Chemical Engineering Progress Monograph Series." The symposium series is designed to bring to the members under one cover various technical symposia sponsored by the Institute or symposia which can be put together from technical papers given at various times. The monograph series in its inception will contain the Institute lecture series, and it is hoped that this can be expanded as time goes on. The symposium series will be indexed each year in a special section of Chemical Engineering Progress. The volumes will carry the same volume number as the current issues of the magazine, as will the monograph series. Since more than one volume is expected to be issued yearly, the issues will carry in addition to a volume number a number and a title. They will be sold at a price designed to cover the cost of printing and handling. Arrangements will be made for the sale of individual volumes or a yearly set may be obtained on an "if, as and when" subscription basis.

James R. Withrow, emeritus professor of Ohio State University, was honored at the Monday night Central Ohio Section party for his long service to chemical engineering. Shown above left to right are: J. H. Koffolt, co-chairman of the meeting and professor of chemical engineering, Ohio State University; Dr. J. R. Withrow and A. W. Davison, Owens-Corning Fiberglas Corp., chairman of Central Ohio Section, who made a presentation of a scroll to Dr. Withrow.

Editor's Note: The Columbus meeting began with the revival of an old custom, an invocation. Dr. Boynton Merrill of the First Congregational Church, Columbus, Ohio, is the author of these words. In listening to them, the Editor was struck by their excellence, and felt that those who were there might like to hear these thoughts again, those not there, might appreciate the opportunity to see them.

Oh Thou who art the Creator and Sustainer of all that lives, Who hast mysteriously given unto us the gift of life and of minds eager and able to learn the truth, and has drawn us into fellowships where, being of kindred concern, we walk the knowledge trails together until they run out past our seeing. We thank Thee for this new day faithfully given out of thy great Treasury of Days. Grant that we may use it wisely to the hurt of none and the good of many.

In these sessions and wherever we shall seek to come on Thy Truth let knowledge grow from more to more and more reverence in us dwell.

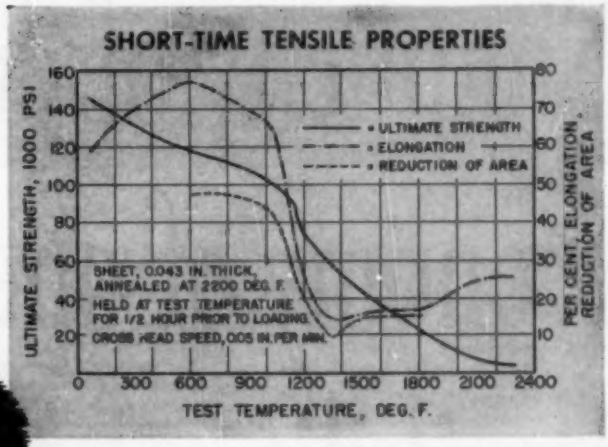
Grant these Thy children here met to experience how good and how pleasant it is for brethren to dwell and to work together in unity. As they shall teach may they teach humbly. As they learn may they learn gratefully, knowing that they are but thinking Thy thoughts after Thee, and are but catching fleeting glimpses of Thy far-off purposes and powers.

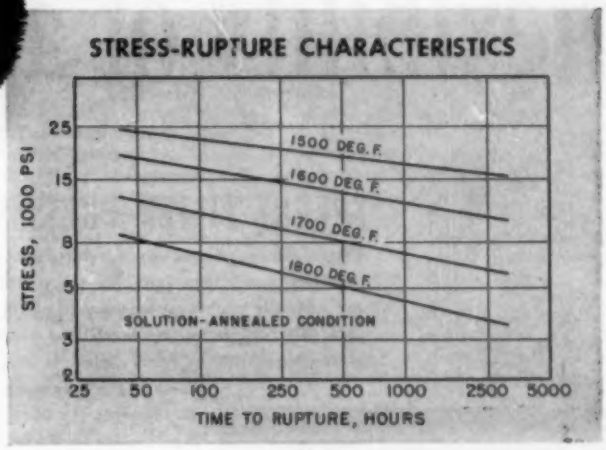
Grant us in all our ways to acknowledge Thee, and may Thou in all our steps direct and keep us.

Graduate Accrediting

Sunday afternoon a panel under the direction of George Granger Brown of the University of Michigan and consisting of A. H. White, professor emeritus of the University of Michgan, Thomas H. Chilton, technical director, technical engineering division of the DuPont Co., Walter G. Whitman, head of the department of chemical engineering of the Massachusetts Institute of Technology, and Marvin C. Rogers, research director of R. R. Donnelly & Sons, explored the idea of accrediting graduate programs leading to M.S. and Ph.D. degrees. Dr. Brown, who is Chairman of the A.I.Ch.E. Committee of Accrediting, said that the goals of the graduate program as envisioned by his committee were: (1) to develop power in the student in applying science to engineering problems; (2) to develop the student's ability to do creative work and to tackle new problems in design or research; and (3) to inspire a student to become an active leader and to develop professional integrity. He then proceeded to list seven minimum requirements for the curricula for a department training successful graduate engineers. Briefly as listed by Dr. Brown for the committee, these requirements are (1) admission of properly equipped individuals; (2) at least two staff members engaged in high caliber professional work in addition to their teaching activities; (3) that a M.S. never be granted for completing courses which are also given in the undergraduate curriculum, the feeling being that graduate work should be on a higher level; (4) the graduate program must include some original research, design, or project; (5) the undergraduate curricula of the school be fully accredited; (6) the over-all environment, facilities and teaching loads must be such as to supply the student with an inspirational atmosphere; and the final point is that the curricula be not rigid, but designed to fit the student. It is the end result which is important, said Dr. Brown, and not the grouping of courses.

(*Continued on page 20*)


SHORT-TIME TENSILE PROPERTIES
ULTIMATE STRENGTH, 1000 PSI
PER CENT ELONGATION, REDUCTION OF AREA
ULTIMATE STRENGTH
ELONGATION
REDUCTION OF AREA
SHEET, 0.043 IN. THICK, ANNEALED AT 2200 DEG. F. HELD AT TEST TEMPERATURE FOR 1/2 HOUR PRIOR TO LOADING. CROSS HEAD SPEED, 005 IN. PER MIN.
TEST TEMPERATURE, DEG. F.



HAYNES
TRADE-MARK
Alloy No. 25

STRONG up to 1800°F. without aging

DUCTILE at room temperature

HAYNES alloy No. 25 is a new wrought high-temperature alloy that has exceptional mechanical properties at temperatures up to 1800 deg. F.—*in the fully annealed condition without subsequent aging.* Yet this alloy is *easy to fabricate* because it has excellent ductility at room temperature. This combination of properties makes HAYNES alloy No. 25 an ideal material for the construction of highly stressed parts that must operate at elevated temperatures.

This latest addition to the series of HAYNES high-temperature alloys was developed as a wrought material to withstand a minimum stress of 6,000 lb. per sq. in. for 100 hours at 1800 deg. F. It is available as sheet, plate, bar stock, and tubing.

Consult our nearest office for engineering data and assistance in solving your high-temperature problems with HAYNES alloy No. 25. Physical and mechanical properties of the other 9 HAYNES high-temperature alloys are given in tabular and graphic form in the booklet, "HAYNES Alloys for High-Temperature Service." Data on short-time tensile properties, stress-rupture, creep test, endurance properties, and fabrication procedures are included. Write to Haynes Stellite Division, UCC, 713 S. Lindsay St., Kokomo, Ind.

Haynes Stellite Division
Union Carbide and Carbon Corporation
UCC
General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

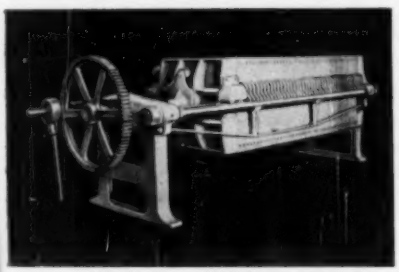
HAYNES
TRADE-MARK
alloys

The trade-mark "Haynes" distinguishes products of Union Carbide and Carbon Corporation.

Simplicity of design, economy of operation, flexibility of application

SPERRY FILTER PRESSES

These three advantages... simplicity, economy, flexibility... are the reasons for the virtually universal acceptance of the plate filter press as engineered for your process operation by Sperry. Here is what these advantages mean.



Simplicity of design results in a minimum investment in processing equipment and a minimum cost for installation. And, once installed, operation is trouble-free.

Simplicity of design results, too, in economy of operation with no skilled or technical personnel required to obtain first quality results. The simplest types of filter cloth and paper may be used just as they are cut from the roll. The filtrate is of maximum clarity, the cake is delivered thoroughly washed and in slab form ready for the drier trays.

Regardless of filter mixture, Sperry presses have the flexibility required to handle it successfully. Pressures and temperatures pose no problem; nor does resistance to acids or alkalies. The liquid need not be exposed to the atmosphere and the filtrate may be delivered to a point higher than the filter. All types of filter bases may be used and varied at minimum cost should your processing plans be revised.

Whatever your filtration problem, you will find the answer in simplicity, economy and flexibility ... the advantages offered by the Sperry plate filter press. Why not put Sperry's fifty years experience to work on this problem now? There is no obligation.

D. R. SPERRY & COMPANY
BATAVIA, ILLINOIS
Filtration Engineers for Over 50 Years

Eastern Sales Representative:
H. E. Jacoby, M. E., 205 E. 42nd St.,
New York 17, N. Y.,
Phone: Murray Hill 4-3581

SPERRY FILTER PRESSES

Western Sales Representative:
B. M. Filhaaby,
833 Merchants Exchange Bldg.
San Francisco 4, Calif.,
Phone: DO 2-0375

Chemical Engineering Progress

DATA SERVICE

BULLETINS

1 • **CORROSION-RESISTANT VALVES.** A bulletin giving a complete history of corrosion-resistant stainless steel gate, globe and swing check valves made by Pacific Valves, Inc. Gives chemical compositions of the materials plus a 4-page article on corrosion. Detail on types of corrosion, corrosion-resistant alloys plus data on corrosive resistance of four types of alloys used in making valves.

2 • **AERATION TOWERS.** Two bulletins on types of aerator towers, air washers, fume stacks, wood pipe, multifin units, etc., made by the Santa Fe Tank & Tower Co. Pictorial in nature, each pamphlet displays the general type of stack, scrubber, etc., made by the company. Other available company bulletins are listed giving specific details on some of the above items.

3 • **BULLETIN INDEX.** A list folder indexing various bulletins available from Schutte and Koerting Co. Folder lists products according to application and alphabetically, with number of descriptive bulletin pertaining to each product.

4 • **FIBERGLAS.** Published by Owens-Corning Fiberglas Corp. an 88-page bibliography of fiberglas articles, third edition. Lists 710 references to articles in 338 publications.

5 • **PHOTOMETER.** A descriptive bulletin of the Photovolt Corp.'s line-operated multiplier photometer. Measures low light values down to 1/10,000 microlumen. Bulletin details application, describes unit, photos of the scales, etc. Used for densitometry, absorption spectrophotometry, light measurements, chromotography, etc.

6 • **SYNCHRONOUS MOTOR CONTROL.** Described in an 8-page booklet, a motor control of all synchronous motor drives. Photographs, line drawings, etc., explain the operation and features of these starters by Westinghouse Electric Corp.

7 • **INDICATOR, CONTROLLER PRICE LIST.** From the Wheelco Instruments Co., a combined condensed catalog and price list which contains description and current price of standard instruments manufactured by this company. Includes pyrometers, potentiometers, flame controls, etc.

8 • **COMPRESSOR.** A new development of the Chicago Pneumatic Tool Co. is a horizontal duplex compressor with roller bearings throughout. Bulletin describes and pictures the construction details of this new line of compressors, shows where bearings are used, how the flood lubrication system works, cylinder design, etc. For chemical engineers with problems in compression of air.

9 • **ELECTRON MICROSCOPE.** A well-illustrated explanation of table model electron microscope made by the RCA instruments division, contains full particulars on features, operation, performance, specifications, operation details, samples of electron microscopy, etc. A digested primer of electron microscope lore.

10 • **FLOAT TRAPS.** Complete specifications, capacity, pressure, sizes and price list of three float traps manufactured by The V. D. Anderson Co. Used to drain condensate from steam, gas and air. Cross sections, applications, specifications. Condensate capacity from 1500 up to 24,000 lb./hr.

11 • **ELECTRONIC CONTROL SYSTEM.** An electronically operated master control system for combustion and process control applications, is announced and described by Republic Flow Meters Co., the Telemaster system. Centralizes control, eliminates transmission lags, gives speedy control response. Works on the null-balance principle. Full description in bulletin and engineering report which shows a typical electronic control system for a boiler. Other advantages claimed are that the new electronic link eliminates dead spots, panel piping, has greater flexibility and reduced maintenance.

12 • **STORAGE BINS.** An explanation of the construction of concrete storage bins by Neff & Fry Co. Main construction feature of the silo is a concrete stave which is formed under 140 tons hydraulic pressure. Has a crushing strength of from 6000 to 8000 lb./sq.in. Bins can be made waterproof and are bound with steel rods. In addition to data of construction, folder lists capacity data and a table of material stored

Mail card for more data ▶

Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1 2 3 4 5 6 7 8 9 10 11 12 14 15 16 17 18 19

20 21 22 23 24 25 26 27 30 31 32 33 34 35 36 37 38 39

40 41 42 43 44 46 50 51 52 53 54 55 56 57 58 59

PLEASE TYPE OR PRINT

Name ..... Position .....

Company .....

Address .....

City ..... Zone ... State .....

Chemical Engineering Progress

DATA SERVICE

such as alumina, calcium chloride, lime, soda ash, etc.

14 • CARBO-KOTE 6020. A Carboline Co. one-page, new product data sheet, on Carbo-Kote 6020, a thermosetting, corrosion-resistant resin. Mixed prior to use, a 10-12 mils. coat is applied with a brush to steel, concrete, wood, glass, carbon, etc. Withstands organic and inorganic acids, solvents, alkalis, etc. Prices given.

15 • V/A CELL. For measuring flow, Fischer & Porter Co. explains in new bulletin the V/A cell kinetic manometer. Uses no mercury and is a direct connected, differential pressure instrument which converts main line flow into proportional air pressure and transmits the air pressure to remotely located receiver instruments such as recorders, controllers or indicators. Applicable to liquid, gas and vapor streams. Data on specifications, air consumption, installation, etc.

16 • JOINT SEALING COMPOUND. A liquid sealer for application to flanged or threaded pipe connections. Resistant to oil, chlorine and other chemicals. Forms an elastic solid. For use in making leakproof threaded joints in piping systems handling inflammable materials under high or low pressures.

17 • DESCRIPTIVE TERMS—STEEL TUBING. Babcock & Wilcox Tube Co. issues for engineers a pocket-sized booklet giving brief descriptions of terminology used in the manufacture and application of steel tubing. Main headings are—Dimensions, Grades of Steel, Surface Finishes, Fabricated Tube Ends, Heat Treatments, Physical Characteristics and Mechanical Properties. Also lists other B & W literature available.

18 • STAINLESS STEEL. Analysis, corrosion resistance, and working characteristics of Carpenter Stainless Steel No. 20. Corrosion resistance to hot sulfuric acid is featured. Analysis of metal, charts of corrosion rate in sulfuric acid, summary of field reports of uses in corrosive installations, plus extensive table of general resistance data.

19 • VOLUMETRIC CHLORINIZER. A bulletin explaining a visible flow chlorinizer which offers a wide range of metering without changing orifices or scales, plus automatic operation and elimination of all heaters since equipment handles only dry, inert chlorine gases. Made by Builders-Providence, Inc. Chlorinizer operates at rates of from 100 to 6000 lb./day. Discusses operation, safety features, rates of flow, maintenance, etc.

20 • CLEANING RUBBER MOLDS. An Oakite Products, Inc., service report of materials and methods specially designed by the company for cleaning molds in the rubber industry. Five methods are described: anodic electrocleaning, heavy duty alkaline cleaning, a combination of the two, solvent cleaning, and steam-detergent.

21 • MIDGET FEEDER. A gravimetric feeder for weigh feeding of dry materials in the chemical industries, is described in a new bulletin by the Omega Machine Co. A capacity of a few cubic inches to 3 cu. ft./min. and a feed range of 100:1 are new features. Bulletin explains all operational and component parts.

22 • CONVEYOR BELTS. A 26-page catalog section on conveyor belts from the B. F. Goodrich Co. All belt features, details of construction, functions of each part, and data on every belt made by the company are included. Gives physical data on strength, longevity, recommended service. Covers special applications for conveyors, elevators, material handling, oil service, package conveyors, food, grain, special constructions, etc.

23 • PHYSICS DIGEST. M. W. Welch Manufacturing Co. issues and offers a quarterly publication containing digests of articles in physics that are considered by it to be outstanding to the teaching profession. Book also contains descriptions of equipment made by the company.

24 • DIELECTRIC MOISTURE METER. A 4-page illustrated bulletin by Weston Electrical Instrument Corp. describing a dielectric moisture meter for test purposes. Used in many industries and on a weighed sample and measures the dielectric constant.

25 • CONICAL BLENDER. A new dry-blending equipment catalog describing a conical blender made by The Patterson Foundry & Machine Co. Includes installation photographs,

Postage Will Be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

BUSINESS REPLY CARD

First Class Permit No. 48890, Sec. 34.9, P. L. & R., New York, N. Y.

Chemical Engineering Progress

120 East 41st Street

New York 17,

New York

USE THESE CARDS

Chemical Engineering Progress

DATA SERVICE

information on the application of the blender to processing applications, etc. Well illustrated it gives specifications, operating power requirements, principle is explained, etc. Used to mix dry powders, colors, pigments, synthetic products, chemicals, fertilizers, etc.

26 • ELECTRONIC LIQUID LEVEL GAUGE. For gauging tanks to within 1/16 in. on a centrally located panel, The Vapor Recovery Systems Co. is offering a bulletin describing the Varec electronic gauger. Uses high precision potentiometers, calibrated in feet, etc. Bulletin describes operation, equipment, gives diagrams of installations, etc. For installation with Varec automatic float actuated gauges and others each transmitter is installed adjacent to the look box of the automatic tank gauge.

27 • CORROSION-RESISTANT METAL. A bulletin giving the composition of Ampco Metal (aluminum bronzes), Gives details of five different alloys, physical properties, corrosion resistance, plus products made such as plug valves, centrifugal pumps, safety tools, sucker rods, etc.

EQUIPMENT

30 • FEED WATER HEATER. For preheating feed water in small power plants up to 300 hp. or less, The Swartwout Co. offers a new all steel "junior" heater. Designed to operate on exhaust steam and designated specifically for small manufacturing plants.

31 • SPECIAL VALVES. A line of valves for actuating air or hydraulic cylinders for hand operation, foot operation, and finger or solenoid operation, by the Ledeen Manufacturing Co. Available in 14 different models, 5 different cycles, 6 sizes. May be used for controlling oil, air, and water. Construction details, dimensions, weights, models, plus other products of the company.

32 • OSCILLATING GRANULATOR. F. J. Stokes Machine Co. announces a new oscillating granulator of welded stainless steel construction. Designed to eliminate leakage of material, hopper is smooth so that cleaning is easy, with motor protected against dust and dirt.

33 • FIRE PROTECTION. A new system for piping dry chemical to hazardous locations by the Ansul Chemical Co. Bulletin explains operation which makes use of a heat-actuated device to set in operation the system for distributing the dry chemical. Can be instrumented to close doors, windows, ventilation ducts, operating valves, shut-off motors, sound alarms, etc. Special distribution heads with caps for locations such as paint spray booths, where spray might clog the head.

34 • VALVE DIAPHRAGM. For high pressure regulators, Rockwell Manufacturing Co. has designed a new diaphragm molded in synthetic rubber and strengthened with nylon fabric. Initially applied to pilot loaded balanced valve regulators, the diaphragm is said to reduce maintenance and reduce pressure variations due to changes in effective diaphragm area.

35 • PROCESS PUMPS. For pumping Dowtherm, hot oil, condensate, propane, etc., and other process liquors up to 800° F., Economy Pumps, Inc. new line of centrifugal pumps. Twelve sizes, capacities from 10 to 1000 gals./min., heads up to 325 ft. Various materials of construction. Features split casing for alignment, water-jacketed stuffing box and bearing housing, and special sleeve.

36 • SILVER ZINC BATTERY. A brochure describing the Yardney Silvercel line of storage batteries using silver and zinc as active materials in an alkaline system. Chargeable, can be used in process work, instrument work, electrochemical work, etc.

37 • MIDGET MERCURY CLEANER. Bethlehem Apparatus Co. has designed a type-F unit for cleaning mercury in 5-lb. lots. Principle of operation is oxidation of impurities and filtration through a special filter. Unit weighs 8 lbs. and requires a table space of only 45 sq. in.

38 • PASTE MIXER. A new model heavy-duty paste mixer of 50-, 100- and 150-gal. capacity, has been designed by Charles Ross and Son Co. Features a right-angled gearhead motor connected directly to the stirrer shaft. Safety cutoff incorporated.

39 • FLEXIBLE ELECTRIC HEATERS. Titan Manufacturing Co., Inc., of-

FOR FREE DATA →

Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1 2 3 4 5 6 7 8 9 10 11 12 14 15 16 17 18 19
20 21 22 23 24 25 26 27 30 31 32 33 34 35 36 37 38 39
40 41 42 43 44 46 50 51 52 53 54 55 56 57 58 59

PLEASE TYPE OR PRINT

Name ..... Position .....

Company .....

Address .....

City ..... Zone State .....

fers for application to pipes, valves, cylinders and containers carrying viscous or free-flowing fluids, chemicals and plastics, etc., a new line of serpentine flexible electric-heating units. The units have a minimum bending radius of ½ in. and have a refractory insulation covered by a steel spring. Standard unit in lengths of from 1 to 10 ft. for 115 or 220 v. There are three types, 5, 10 and 15 watts/in. for 475°, 650° and 700° F.

40 • SEPARATORS. For removing liquids and solids from steam, air, etc., The Swartwout Co. line of separators operating on the helico-centrifugal principle. Air or steam is given a centrifugal motion, liquids and solids are thrown against the wall of the separator and run to a drip pocket. Variety of styles, sizes from 1½ in. to 24 in. and from 50- to 600-lb. pressure.

41 • BAG FLATTENER. For flattening bags the Flexoveyor Manufacturing Co. has designed a combination bag flattener and pallet loader. Series of endless steel coil springs running over grooved steel conveying medium and a tension spring and rocker arm connection between upper and lower conveyors, gives a kneading and pressing action to each bag so that air is eliminated and the contents evenly distributed. A 30% saving of space claimed.

42 • MULTISTAGE CENTRIFUGALS. Ingersoll-Rand Co. has a new line of multistage centrifugal pumps for high pressure applications to 1200 lbs./sq.in. and capacities of 1600 gals./min. Sizes, 3 to 6 in. with 3 to 9 stages. Details of pump, application, sizes, etc., explained in the bulletin.

43 • PORTABLE ION-EXCHANGE UNIT. For pilot plants, Artisan Metal Products, Inc., with a new portable ion-exchange unit. Consists of six 4-in. glass columns in stainless steel frames. Piped for series operation with copper pipe and brass gate valves. Unit can be backwashed and regenerated similar to commercial units.

44 • GASKETED PLUG VALVE. Niagara Filter Corp. announces a double seal cock with two O ring gaskets recessed in the cock plug above and below the flow port. Eliminates dripping at pressures up to 75 lbs./sq.in. Owing to the hard rubber gaskets the cock turns easily without balling or binding.

46 • ELECTROMAGNET. Arthur D. Little, Inc., announces the production of an electromagnet for use in research demanding high flux density magnetic fields. Model weighs 4000 lbs. Compact unit can be had in either adjustable or fixed height model.

CHEMICALS

50 • ACIDPROOF CEMENT. Nukem Products Corp. announces an acidproof cement of a furfural alcohol resin base for setting brick sheathing in pickling tanks, sewers, chemical process tanks, industrial floors, etc.

51 • FOAM STABILIZING AGENT. Masonite Corp. has just introduced Masonoid CTM, a new product for use as a foaming or foam-stabilizing agent for foamed glues, foamed insulation, tracer foams, chemical foams, low density paper and board products, etc.

52 • PHTHALATE PLASTICIZERS. A bulletin on phthalate plasticizers released by Pittsburgh Coke & Chemical Co. Covers three ester plasticizers of special interest to the vinyl resin, rubber, and protective coating industries. DiButyl Phthalate, a DiIsoOctyl Phthalate and a DiOctyl Phthalate. Data sheets have table of properties, description of uses, indication of compatability, specification, etc.

53 • SUCROSE OCTA ACETATE. Niacet chemicals division data sheet gives specifications, physiological aspects, chemical properties, applications, etc.

54 • PURIFYING METAL SOLUTIONS. An article on the use of hydrogen peroxide for purifying metal salt solutions from the Buffalo Electro Chemical Co. Gives directions for isolating metal salts from process solutions for the following: electrolytic nickel plating, beryllium production, magnesium production, phosphatizing, optical glass production and tin recovery.

55 • SYNTHETIC CARBAZOLE. Available quantities from Reilly Tar & Chemical Corp. synthetic carbazole ($C_{12}H_9N$) for use in the hydrone series of dyes, can be used also in interaction with acetylene to form vinyl carbazole, etc. Full details available.

56 • GLYCERINE FACTS. Another issue of a publication by the Glycerine Information Service for those interested in using glycerine. This issue covers various phases such as alkyd resins for marine paints, nonclogging fuel oil, printing ink, gelatine in glycerine, pectin preparations, floor and wall coverings, etc.

57 • FLUORINE COMPOUNDS. Pennsylvania Salt Manufacturing Co. announces three organic sulfonyl fluorides, benzenesulfonyl fluoride, *p*-chlorobenzenesulfonyl fluoride and *m*-nitbrobenzenesulfonyl fluoride. Compounds are thermally stable and resistant to hydrolysis. Slated for use as solvents, heat-transfer agents, intermediates and chlorination media.

58 • FLATTING AGENT. For use in lacquer manufacture The Davison Chemical Corp. has introduced Syloid 308. Gives control over the degree of matte finish.

59 • SYNTHETIC ORGANIC CHEMICALS. The Niacet chemicals division of Union Carbide & Carbon Corp. offers a 52-page catalog on synthetic organic chemicals which presents in detail the physical and chemical properties, latest specifications, applications, shipping and handling information on Niacet's chemicals—acetic acid, acetates, acetaldehyde, acetonitrile, etc.

Postage Will Be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

BUSINESS REPLY CARD

First Class Permit No. 48890, Sec. 34.9, P. L. & R., New York, N. Y.

Chemical Engineering Progress

120 East 41st Street

New York 17,

New York

GILLILAND

(*Continued from page 12*)

we are to make real progress in one of our major requirements.

The foregoing comments indicate that in my opinion our basic concepts of the mechanism of mass transfer are unsatisfactory. On the other hand, it would apppear that several basic uncertainties could be clarified by relatively simple research programs. It should be a fruitful field for thesis work.

These remarks were largely related to the mass-transfer operation, but similar comments apply to almost every phase of chemical engineering. In almost every case the chemical engineer has done a good job of applying principles and concepts developed by other groups. If our field is going to continue to progress at a rapid rate, we must develop more of the fundamentals.

Leaving our specific field, I am going to take this opportunity to comment on a trend in engineering research in general that is important to all of us. For the past ten years a high percentage of all research and development work in the United States has been financed by the Government, particularly the military services plus the Atomic Energy Commission. This may be inevitable with the present state of the world. While it is difficult to obtain satisfactory estimates, the Government expenditures for research and development are apparently from one to two times the total for industry plus universities.

The Government-sponsored research must involve the effort of a large proportion of the scientists and engineers of the country. A considerable portion of this money has gone to the universities, and large research and development programs are involved in a number of chemical engineering departments. There are several aspects of this problem that need serious consideration. There is a tendency to channelize research and development work into certain fields at the expense of others of equal importance. Some of the neglected fields will be probably of more importance in a real emergency than some of those being actively pushed. I question whether the military services have sufficient background in science and engineering to direct a major part of the research effort of the country even for their own greatest benefit. The Research and Development Board of the Defense Department has organized civilian groups to work with the service members to aid in guiding this work. As a result of serving on several committees and panels of the R. D. B., I am even more concerned

(*Continued on page 22*)

ANSUL SO_2 is a volatile, easy to control, *multi-purpose* acid. It permits the user to . . . . 1) combine a number of individual process steps into one simple operation . . . . 2) easily remove many product impurities sometimes difficult to eliminate . . . resulting in *improved process efficiency* and *better quality control* of the finished product.

LIQUID Sulfur Dioxide ANSUL* 99.98% (by weight) PURE

*REG. U. S. PAT. OFF.

Write for Bulletin No. 0-109 for more information and if possible, include a description of the application in your plant. Our Technical Staff will help you take full advantage of the benefits outlined above. In addition to our Bulletin describing the Ansul Constant SO_2 Concentration System, we will send you an informative treatise describing the properties, characteristics and industrial uses of Liquid Sulfur Dioxide . . . An Ansul Technical Staff Publication.

For your METHYL CHLORIDE applications Use ANSUL METHYL CHLORIDE

ANSUL CHEMICAL COMPANY
INDUSTRIAL CHEMICALS DIVISION, MARINETTE, WISCONSIN
60 E. 42nd St., New York · Lincoln-Liberty Bldg., Broad & Chestnut Sts., Philadelphia 7, Pa.

COLUMBUS MEETING

(*Continued from page 16*)

Top picture, left to right: Registration Committee at Columbus, W. G. Jurevic of Battelle Memorial Institute; I. N. Smith, Fiberglas Corp., and R. Kreager of Ohio State University. Second picture shows some of the members on the panel on graduate accrediting, W. G. Whitman, M.I.T.; M. C. Rogers, R. R. Donnelley & Sons, and A. H. White, professor emeritus, University of Michigan. Below that are members of the Committee on Student Chapters at a breakfast meeting, G. M. Brown, Northwestern Tech. Inst.; D. L. Katz, University of Michigan; J. S. Walton, Oregon State College and chairman of the committee; C. C. Monrad, Carnegie Institute of Technology, and W. L. Kranich, Worcester Poly. Inst. The last picture, left to right: C. G. Kirkbride, Houdry Process Corp.; J. D. Lindsay, Texas A & M, and M. T. Howerton, University of Notre Dame.

The next speaker on the panel, A. H. White, said that the need for accrediting graduate programs in chemical engineering could be directly traced to the growth of the profession, and that we had reached the point where we had a need for rigid standards and requirements.

T. H. Chilton then addressed the audience on the industrial viewpoint of the objectives for graduate work in chemical engineering. He said that industry looks for several qualities in a graduate student, the primary requirements being the ability to tackle the more difficult problems in research and development, and the ability to improvise and find appropriate solutions to unique problems, even though the answer had never been thought of before. In addition, he said, industry expects a more mature viewpoint from a graduate student, and greater adaptability and flexibility in approaching and solving a problem. One further quality was stressed by Dr. Chilton, that the graduate student must have an understanding of research techniques.

Professor Whitman stated in his talk that the predominant factor in any program for graduate study is the competence of the teaching staff to give advanced work. He felt the competence should exist not only in the professional field, but the staff should be interested in research, and competent to supervise it. This was Whitman's main theme, though several other ideas were stressed during his talk. He held that the subject of graduate research is not vital, and that a thesis was merely an opportunity for a man to learn to do something on his own. This was all that educators should try to do when they insisted on a thesis. It followed then, he said, that the staff must represent a quality of leadership that they are trying to develop in a man. He felt that admission to a graduate school should be selective, and should not be opened solely to those who could afford the time and money for it. He suggested that graduate schools be open only to those in the upper third of a class, the criteria being not marks, but "potential ability." Whitman's argument was rounded out by stating performance of students should be high, and that schools should have other graduate programs in other departments, since the association of staff and student was important and valuable.

The final panel member, Marvin C. Rogers, speaking from an industrial viewpoint, thought that graduate training should be a privilege, and those who take it must meet some requirement in order to avail themselves of the advanced work. He said that the development of the individual was the important thing, not the monetary gain expected from obtaining an advanced degree. High mental ability should be stressed, he said, but the engineer should not be allowed to build in a shell of specialization. Industry expects a graduate student to have creative ability, work independently, and to show originality, and have some indication of professional integrity and leadership.

Awards

Institute awards were given at a special banquet held Tuesday, Dec. 3, and at that time, as announced last month in Chemical Engineering Progress, Prof. E. R. Gilliland of M.I.T. received the Professional Progress Award in Chemical Engineering, sponsored by the Celanese Corporation of America. His address "Problems in Chemical Engineering Research," is published on page 11 of this issue. The William H. Walker Award went to Barnett F. Dodge, professor of chemical engineering and head of the department of chemical engineering at Yale University in recognition for his outstanding contributions to the literature of chemical engineering over the years; the Junior Award went to F. M. Tiller, associate professor of chemical engineering at Vanderbilt University for his outstanding contributions to the literature of chemical engineering; and the winner of the A. MacLaren White Award was Robert P. Bannon, a chemical engineering graduate of the University of Illinois, June, 1950, for his solution of an engineering contest problem.

One other prominent chemical engineer was honored at the meeting when the Central Ohio Section presented a scroll to James R. Withrow, emeritus professor and former head of the department of chemical engineering at Ohio State University. The recognition was made to Dr. Withrow for his long connection with, and pioneering work in, chemical engineering education in Ohio. The scroll of testimony was presented by Dr. A. W. Davison, research director of Owens-Corning Fiberglas Corp., and president of the Central Ohio Section of the A.I.Ch.E. Following the award presentation the nationally recognized Symphonic Choir of Ohio State University performed for the gathering, under the direction of Prof. Louis H. Diercks.

Second Institute Lecturer

Olaf A. Hougen, professor of chemical engineering of the University of Wisconsin, delivered the Second Institute Lecture on "The Status of Applied Kinetics." The complete manuscript will be published in what will probably be the first Chemical Engineering Progress Monograph Series. In his lecture Professor Hougen dwelled on the enormous amount of work yet to be done in the field of kinetics before the mechanisms are completely understood.

Space limitations prevent the lecture and technical papers from being reported in this issue, but the Editor plans

(*Continued on page 28*)

Another Important Instrumentation Development by Beckman . . .

✱Greater Compactness
✱Higher Accuracy
✱Lower Sample Consumption
✱Maximum Convenience

THE NEW BECKMAN
Flame Photometry Attachment
FOR BECKMAN "DU SPECTROPHOTOMETERS

To meet the steadily growing interest in flame spectrophotometric methods, Beckman engineers have developed a new Flame Photometry Attachment that sets greatly advanced standards of compactness, convenience, accuracy and simplicity.

Used with the Beckman "DU" Spectrophotometer and standard oxy-hydrogen or oxy-acetylene equipment, it combines the unusually high accuracy and resolution of the well-known Beckman "DU" with the conveniences of flame spectrophotometric methods, providing an instrument capable of the quantitative determination of more than 40 elements, including heavy metals and rare earths, as well as the alkali metals.

The atomizer-burner of this new instrument is much smaller, simpler and more trouble-free than previous designs. Made of Pyrex with a straight, large-diameter, noble-metal atomizer tube discharging directly into the flame, it will spray even cloudy or highly concentrated solutions indefinitely without clogging or "drifts".

Other important features of this new Beckman development are outlined at right. Best of all, this new instrument is available at a new low price for equipment of this quality. Your nearest authorized Beckman instrument dealer will gladly supply full details—or write direct!

BECKMAN INSTRUMENTS INC

SOUTH PASADENA 35, CALIF.

Factory Service Branches: Chicago • New York • Los Angeles

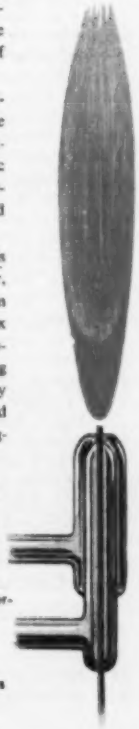


Illustration at right shows atomizer-burner actual size.

Outstanding Features of the New Beckman Flame Photometry Attachment

- Sample beaker is supported in a unique mechanism that swings the beaker outside the case for easy filling, or swings it back into position below the burner tube. Further, as the beaker is raised into position below the burner, it automatically tips so that sample solution is drawn from lowest point in beaker. Thus, complete analyses can be made with even extremely small samples.
- The atomizer requires only about 2 ml of sample solution per minute, and a sample of 1 to 3 ml is ample for determination of several constituents.
- Fuel consumption is very low—about 5 cu. ft./hr. for acetylene, 8 cu. ft./hr. for oxygen, 20 cu. ft./hr. for hydrogen.
- The hot flame, coupled with the high resolution of the "DU" Spectrophotometer, permits unusually narrow band widths to be used—less than 10 millimicrons for most determinations. Accuracies of 0.5% or better are obtainable.
- Sample concentration is unimportant (provided it is above the lower detectable limit) permitting maximum versatility and convenience in making analyses.
- Although the sensitivity of most elements is improved when the elements are in water solution, non-aqueous solutions are as easily handled as water. Even combustible solvents can be used—and in fact, organic solvents frequently increase sensitivity of the readings.
- The atomizer-burner, sample-positioning device, focusing mirror and adjustments are all unitized into a compact, cast-metal housing. All necessary regulators and gauges (except standard regulators on fuel and oxygen tanks) are conveniently mounted on a separate control panel.

Write for complete details on this important new Beckman advancement!

GILLILAND

(*Continued from page* 19)

about the lack of any real study of the implications of this vast program. The R. D. B. setup does not appear to be an effective organization for guiding this program. There has been no comprehensive analysis by any of the groups involved of the over-all research problems of the country. We need such a study by a group of outstanding men who can take an over-all view of the requirements of our country under present world conditions. They could consider how to utilize our technical manpower to the best advantage. They could consider whether we needed to train more scientists and engineers or whether these men should be in the armed services instead of in school. The present method of making such decisions on a piecemeal basis is dangerous.

As engineers, we have a major obligation to our country, particularly for its defense and security. However, I am concerned over the fact that one of the main contributions of science and technology is for destructive purposes. I hope that the public does not arrive at the conclusion that the chief contribution of our field is destruction. While technically trained people are a necessity in modern warfare, I hope that we can sell the public the view that our main contributions are for the social good and not for destruction. We should make a real effort along this line. It is not sufficient to take the viewpoint that science and technology are neutral and that the harmful effects are only in the way they are applied. To a considerable degree the different phases of technological endeavor can be differentiated as to those that are likely to make sociological improvements compared with those that will make their major effect along military lines. It is not possible to foresee the whole outcome of any technical development, but, with our understanding of human nature, developments that lead to improved living conditions, such as better housing, better medicine, better nutrition, are much more likely to be important sociologically than is the development of long-range rockets. While it is difficult to refuse money for an intriguing technical program, we should conscientiously consider the social implications of any work we undertake. We should concentrate our efforts along those lines which we believe will be most beneficial. It is not enough for us to take a neutral position relative to science and engineering and put the blame on others.

Award address given by Dr. Gilliland at the A.I.Ch.E. Meeting in Columbus, Dec. 3-6, 1950.

TRAINEES NEEDED FOR A.E.C. REACTOR SCHOOL

Applications are now being received by the Oak Ridge School of Reactor Technology for enrollment in the 1951-52 session, beginning Sept. 10, 1951. This school was established at the Oak Ridge National Laboratory in March, 1950, under sponsorship of the U. S. Atomic Energy Commission. Its purpose is to train engineers and scientists in the field of reactor theory and technology, in preparation for their employment in this field by the AEC or its contractors.

The Oak Ridge School of Reactor Technology will enroll students of outstanding qualifications who hold, or will receive by September, 1951, bachelor's or master's degrees in chemistry, engineering, metallurgy or physics. A limited number of recent college graduates will be accepted under category *A* in the status of student-employees of the Oak Ridge National Laboratory, and will be paid a monthly stipend for a 12-month period, beginning September, 1951.

Provision is also made for trainees sponsored by government agencies and industrial organizations connected with or interested in the AEC reactor development program, Category *B*. Applications for enrollment under this category must be made by the firms or agencies employing the applicants. Such students remain on the payrolls of their home organizations.

Much of the material presented in the curriculum of the Oak Ridge School of Reactor Technology will be classified; hence, all enrollments are contingent upon a personnel security investigation.

Men trained in chemistry, engineering or metallurgy are much in demand in the reactor development program. It is the purpose of the Oak Ridge School of Reactor Technology to provide engineers and scientists with sufficient background in reactor technology and allied subjects to become effective as research, development and design personnel.

Further information and application forms may be obtained by writing to the Director, Oak Ridge School of Reactor Technology, Post Office Box P, Oak Ridge, Tenn. Category for which application is requested must be specified. These applications must be filed with the director of the school by March 1, 1951. Announcements of appointments will be made in April, 1951.

U. S. ENGINEERS ADDRESS CANADA CONFERENCE

Several chemical engineers from the United States are expected to address the Conference of the Chemical Institute of Canada, chemical engineering division, at Toronto, Feb. 19 and 20, 1951.

Prof. W. H. McAdams of M.I.T. will address the conference on, "Heat Transfer." Another speaker will be Dr. T. H. Chilton, technical director of the development engineering division, Du Pont Co., Inc.

Dr. R. L. Pigford, chairman of the department of chemical engineering at the University of Delaware, will present a paper, as will Dr. J. A. Taylor of Wayne University, and Dr. W. H. Stark, general manager of the Vickers-Vulcan Processing Co.

NEW CHEMISTRY BUILDING FOR U. OF I.

Dedication of the new East Chemistry building at the University of Illinois will be March 30 and 31, 1951, according to the board of trustees.

Dedication events will include a symposia on chemical engineering and another on biochemistry, with four distinguished speakers for each.

The new building and its equipment are valued at $3,400,000. A feature is a central room more than 70 ft. high for erection of distillation columns.

E.J.C. NOMINEES ON N.S.F. BOARD

Donald H. McLaughlin, Edward L. Moreland and Audrey A. Potter were named recently by President Truman as members of the 24-man Board of National Science Foundation. These three engineers were among the nominees presented to President Truman by Engineers Joint Council of which the A.I.Ch.E. is a member. With the EJC list of nominees went a strong recommendation that applied science, as represented by engineers, be given appropriate consideration on the Board of National Science Foundation.

Mr. McLaughlin is president of the Homestake Mining Co., Mr. Moreland is a principal in the consulting engineering firm of Jackson and Moreland and Mr. Potter is dean of engineering at Purdue University. The other members of the board, as named by President Truman, all subject to confirmation by the Senate, are Detlev W. Bronk, James B. Conant, John W. Davis, Charles Dollard, Lee A. Dubridge, Edwin B. Fred, Frederick A. Middlebush and George D. Humphrey, all university presidents; Percy Barnes, Gerti T. Cori, Paul M. Gross, O. W. Hyman, Robert F. Loeb, Joseph C. Morris, Harold M. Morse and Henry Yancey, all deans or professors of university science departments; Sophie D. Aberle, James A. Reyniers, Elvin C. Stakman, science laboratory chiefs; Charles E. Wilson, president, General Electric Co., and Chester I. Barnard, president, Rockefeller Foundation.

(*More News on page* 25)

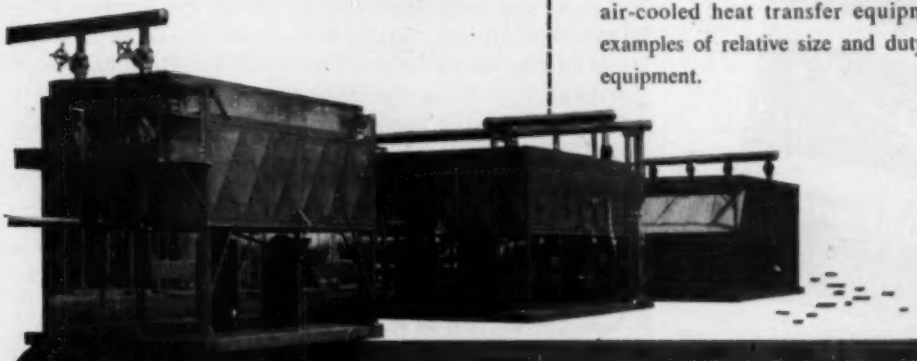
Here are 15 TYPICAL APPLICATIONS for

FIN-FAN

AIR-COOLED

Heat Exchanger Equipment

For many years, Fin-Fan Air-Cooled Heat Exchangers have proved their worth by giving reliable, economical service in many and varied applications. The Fluor Corporation, Ltd., and Griscom-Russell Company, pioneer-partners in the air-cooled heat transfer field, offer the following to show the large variety of practical applications for air-cooled heat transfer equipment and examples of relative size and duty of such equipment.



GAS COOLING	Natural Gas After-Cooler	13,920,000	80	46' x 25'
	Manufactured Gas Cooler	11,165,000	50	23' x 21'
	Natural Gas After-Cooler	3,400,000	15	11' x 21'
	Natural Gas Inter-Cooler	7,890,000	40	23' x 21'
VAPOR CONDENSING	Reflux Condenser	18,407,000	90	48' x 25'
	Primary Condenser	4,652,000	40	11' x 25'
	Still O.H. Condenser	4,875,000	34	16' x 21'
	Debutanizer Condenser	11,930,000	60	23' x 25'
	Still Reflux Condenser	39,110,000	60	46' x 25'
	Steam Condenser	87,300,000	300	138' x 31'
	Steam Condenser	2,880,000	10	10' x 6'
LIQUID COOLING	Vegetable Oil Cooler	628,000	15	6' x 17'
	Absorption Oil Cooler	14,915,000	100	32' x 17'
	Quenching Oil Cooler	1,665,000	50	23' x 25'
	Amine Solution Cooler	19,300,000	175	38' x 25'
	Stabilized Crude Cooler	125,100,000	700	315' x 25'
	Jacket Water	2,400,000	5.5	16' x 12'
	Jacket Water	28,800,000	100	70' x 24'

A new 8-page bulletin on Fluor-GR Fin-Fan Heat Exchangers is now being prepared. Write in and reserve your copy by post card or letter.

FLUOR

Why Fluor-GR Fin-Fans Lead The Field

The Fin-Fan Air-Cooled Heat Exchanger is unique in its development and manufacture. It is the result of the engineering skill of *two* companies, *each* long recognized as leaders in their respective fields. It combines Fluor's experience in the design, fabrication and field erection of air-moving systems with Griscom-Russell's experience in heat transfer.

Success is evident in repeat orders. Since 1941, hundreds of Fluor-GR Air-Cooled Heat Exchangers have been installed throughout the world . . . nearly 50% have been repeat orders!

BE SURE WITH FLUOR

ENGINEERS • CONSTRUCTORS • MANUFACTURERS

THE FLUOR CORPORATION, LTD., 2500 S. Atlantic Blvd., Los Angeles 22, Calif., *Offices in principal cities in the United States*

REPRESENTED IN THE STERLING AREAS BY: Head Wrightson Processes Ltd., Teesdale House, Baltic Street, London, E.C.1., England

Problem: How to Handle with Safety Highly Viscous Materials Under Pressure

Chemical engineers of many of the nation's largest industrial plants have watched with interest development of the NEW BS&B T-ASSEMBLY SAFETY HEAD. It is already in demand. It is recommended for chemical plants handling viscous materials.

No other relief device acts as quickly as the BS&B SAFETY HEAD. It consists of three principal parts... a pre-formed metal rupture disc and two specially designed holding flanges. Correct element resistant metals are used in fabrication of the rupture disc, which bursts when a predetermined pressure is reached. Instantly a fully unrestricted escape for gases and liquids takes place. And, as quickly the possible dangers of property damage, fires and injuries to personnel vanish.

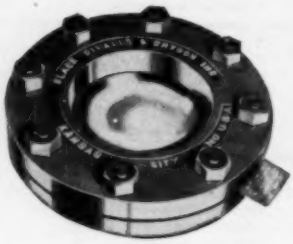
Send for This Catalog Now!

The BS&B SAFETY HEAD story is fully covered in a new catalog. Send for your free copy NOW! Use coupon on the opposite page. Once you understand your need for SAFETY HEADS, you won't delay.

Free Analysis Without Obligation

Jim Myers, SAFETY HEAD Sales Manager will have a BS&B engineer analyze your pressure relief problems and submit suggestions to you WITHOUT COST OR OBLIGATION. Mail coupon on opposite page or call GRand 6700, Kansas City, Mo. DO IT NOW!

Do You need T-ASSEMBLY SAFETY HEADS?

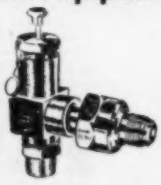


The answer is YES . . . to every chemical plant using viscous materials under pressure provided the liquid contacts the metal rupture disc. Such plants should not be without this new positive protection relief device. Read the details on "How a T-ASSEMBLY SAFETY HEAD Works" on the opposite page. This newly designed T-Assembly unit is the combined art of the highest achievement of metallurgical and engineering skill.

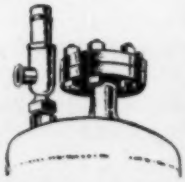
Here Are Your Answers to Relief Valve Problems--Extra Protection for Expensive Equipment

This installation is used when it is not necessary to have a shut-off or when materials handled are not toxic or inflammable.

A SAFETY HEAD at the relief outlet will stop leakage until rupture disc pressure is attained. Not recommended where viscous or corrosive materials might contaminate internal parts of the valve. Investigate your valve design before using this type of installation.

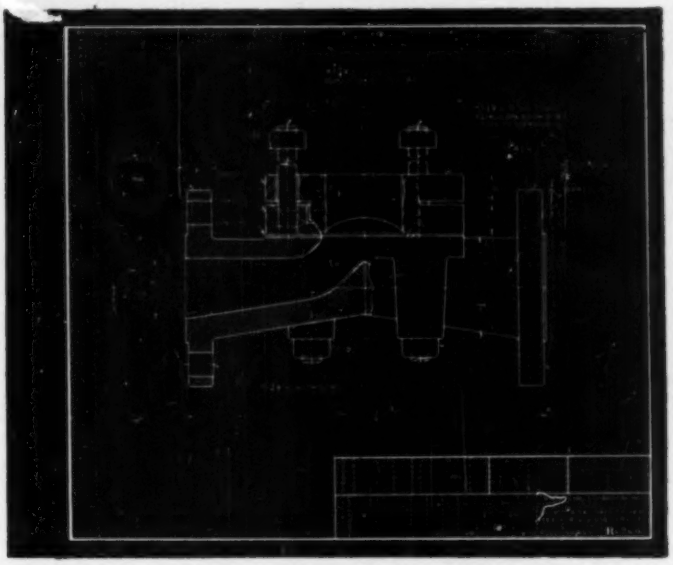


A SAFETY HEAD under your relief valve isolates the valve from the vessel contents. This stops leakage through relief valve until SAFETY HEAD disc is burst by overpressure. An open bleed line or some type of telltale indicator must be installed in chamber between rupture disc and valve plug.



When the SAFETY HEAD is used as secondary relief device you are given positive protection when pressure rises to the predetermined bursting pressure of the rupture disc. The primary relief valve may fail to function due to corrosion, or pressure continues to rise due to inadequate relief area

Solution: ....BS&B T-ASSEMBLY SAFETY HEADS



How the T-ASSEMBLY SAFETY HEAD Works

The shaded portions of the above diagram indicate a curved channel designed by BS&B through which the viscous material washes against the rupture disc. This material moves on through the passage if no undue pressure rise occurs. However, if the passage becomes blocked, such material will tend to solidify quickly, causing a dangerous pressure rise. In that case, the SAFETY HEAD rupture disc bursts and the pressure is given a fully unrestricted opening.

BLACK, SIVALLS & BRYSON, INC.

Special Products Division

KANSAS CITY • TULSA • OKLAHOMA CITY

SALES PROMOTION DEPT.
BLACK, SIVALLS & BRYSON, INC.
7502 E. 12th St., Sec. 2A-92-1 Kansas City, Mo.

☐ Please send a copy of the BS&B SAFETY HEAD catalog.
☐ Please have a BS&B SAFETY HEAD engineer analyze my relief problem, without cost or obligation to me.

Name_____
Firm_____
Title_____
Address_____
City_____ Zone_____ State_____

BS&B SAFETY HEADS

NEWS

(*Continued from page 22*)

CONFERENCE ON INDUSTRIAL PERSONNEL

A "Conference on Industrial Personnel" at Columbia University, New York, will be held March 19 to 23, 1951, according to Prof. William W. Waite, head of personnel area of the Columbia department of industrial engineering, and director of the conference.

Under the theme of "The Frontiers of Personnel Administration," new concepts of personnel administration will be presented in lectures and round-table clinic discussions between authorities on various phases of personnel administration and representatives of approximately 50 leading industrial and business concerns.

Of major interest, Professor Waite said, is the fact that "each company represented will send both a top personnel executive as well as a first-line supervisor to the conference. We believe this is the first time that foremen, who must implement and carry out policies, have had an opportunity to express, in such a conference, their thoughts and reactions to personnel administration ideas in the formative stage."

TRACERLAB HAS EXPANSION PLANS

Tracerlab, Inc., will purchase a building site of approximately 17 acres in West Concord, 18 miles northwest of Boston, for construction of a new building to house engineering and manufacturing operations.

It is contemplated that the first unit to be built on the West Concord site will be to handle additional instrument production and radiochemical laboratories in connection with the current expansion program. There are no immediate plans to move the offices and laboratories in downtown Boston to the new site.

SHELL EXPANDS AMMONIA PRODUCTION

Plans for substantial expansion of Shell Chemical Corp.'s synthetic ammonia plant at Shell Point, near Pittsburg, Calif., were announced recently by J. Oostermeyer, president of the company. Equipment for the new expansion will be completed and in operation by next spring. The latest expansion will represent an increase in output of more than 300 per cent during the past ten years.

(*More News on page 28*)

CRITICAL SHORTAGE OF ENGINEERS*

OUR country is again obliged to arm in an effort to preserve peace, or to repulse attack if it should come. We are greatly outnumbered and our only chance of survival depends upon our ability to out-design, out-develop, out-produce, and out-perform our opponents. In these efforts engineers are essential. But we are short of engineers. The shortage of engineers will become still more acute if they are called for military service and used in positions for which their training and experience are not mandatory.

The chart (Fig. 1) presents the essential factors in the outlook for the supply of engineering graduates. The lower curve shows that from 1942 through 1945 the country all but stopped the operation of engineering education.

The dotted line, extended beyond 1950, shows the estimated number of graduates if the schools operate without any withdrawals by Selective Service. It represents the most optimistic production possible, at least until 1954, since all classes graduating up to that year are already enrolled.

Beyond 1950, a dotted line indicates the estimated freshman enrollment. This estimate, made before the Korean War, was based on peacetime expectancies. The chief reason why the 1950 enrollment did not reach the estimate was the widespread rumors that the engineering field was over-supplied.

The demand for engineers already shows tightness in all fields, especially in the aeronautical, chemical, electrical, and mechanical fields. Industry has absorbed the last two graduating classes of nearly 50,000 each and is hotly contending for the 30,000 that will graduate in 1951. Many are in ROTC programs and will go direct to military service; others who have draft postponements will be subject to call. The Secretary of Labor has placed all branches of engineering on the list of critical occupations. The shortage is becoming more critical.

* Adapted from a Report to E.J.C.'s Engineering Manpower Commission, by S. C. Hollister, Dean, College of Engineering, Cornell University, Ithaca, N. Y.

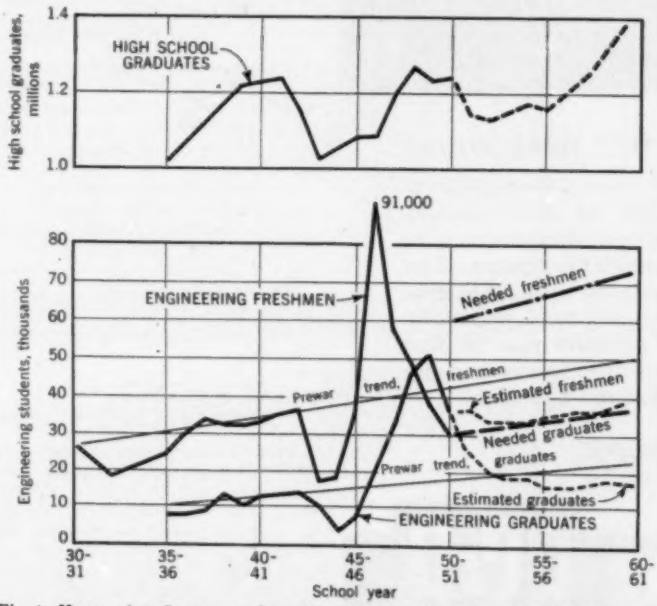


Fig. 1. Veteran benefit program brought unprecedented number of 91,000 freshmen into engineering colleges in 1946, but number has since fallen rapidly, to about half that estimated as essential by Dean Hollister.

Normally in peacetime at least 20,000 engineering graduates are required annually. But after absorbing 50,000 in each of the last two years, industry still does not have all it needs. And the military needs have not yet been assessed. Thus the minimum annual need appears to be not less than 30,000.

The question now is: How can we obtain 30,000 engineering graduates yearly? Mortality in the engineering colleges is about 50 per cent, so an annual input of 60,000 freshmen would be required—double the number that entered the schools this year. How can twice as many high school graduates be attracted to engineering schools?

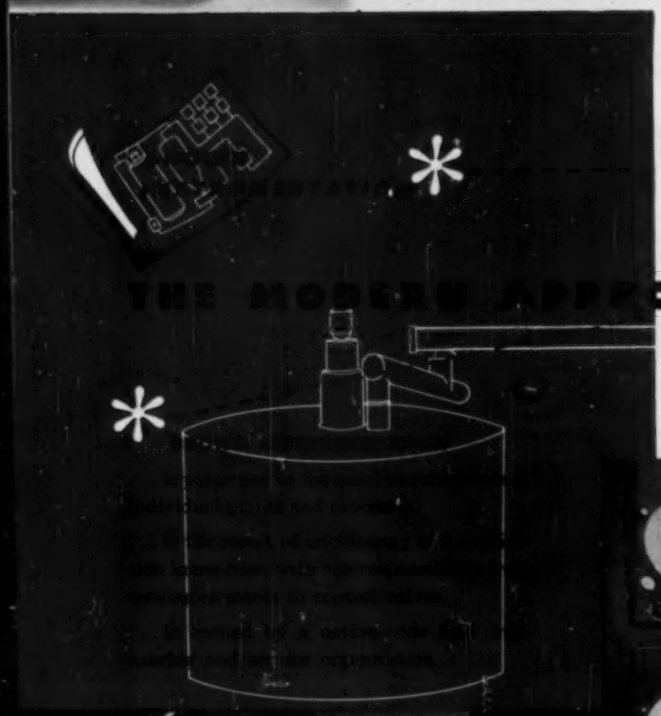
Since a dip of 10 per cent in high school graduations is expected between 1950 and 1958, we cannot rely on an increase in the output of the high schools to solve the problem.

Since 1935, except for the war and immediate postwar years, 2.7 to 3.1 per cent of the total high school graduating classes entered engineering schools. On the basis of an average high school output of 1,200,000 boys and girls, 5 per cent would be required to produce 60,000 engineering freshmen, or about 10 per cent of the boys. There is doubt whether the combined factors of aptitude, ability, interest, etc., can be found in so high a percentage. The fact is that there is not, and cannot be developed, an inexhaustible supply of engineering talent.

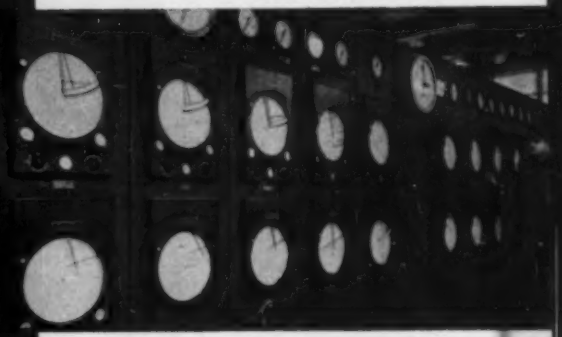
It is essential that all avenues of information be utilized to acquaint high school principals, counselors, and students with the shortage of engineers in all fields.

What is significant to industry in this picture, apart from the short supply of engineers? Company pirating will only add to the difficulties of staffing, and robbing the colleges of faculty members will dry up the supply and reduce the quality of training. Industry must re-examine the functions of engineering personnel and make certain that each engineer is being used in the most effective manner. Even competent supporting personnel will be tight. In-service training of supporting personnel must begin and engage women as far as possible. The training programs of the last war will need to be re-established. None of these steps can be put off.

Government agencies must take cognizance of this situation and plans must be developed for coordinating the engineering manpower needs of the Services and of industry. To assume that the need for engineers is exclusively military would be national suicide. Sound policies for deferment and the calling of reservists must be promulgated with the objective of maintaining a balanced utilization.



THE MODERN APPROACH to *Solvent Extraction*



CONTINUOUS solvent extraction is the modern method of extracting vegetable oils in use at the Glidden Company's new plant in Indianapolis. This plant, constructed by Blaw-Knox and utilizing their Rotocel, incorporates advanced engineering and instrumentation techniques to obtain maximum yields of soybean oil at lowest costs.

The entire operation is automatically controlled by Brown instruments mounted in a centrally located board. Indicating and recording temperature, pressure and flow controllers comprise a coordinated system of Brown instruments that maintains critical variables at their desired values.

When looking for automatic recording and controlling instruments for your solvent extraction operations, or *any chemical process—consider first*

- *The Brown know-how developed through many years of application experience in the industry.*
- *The completeness of the Brown modern approach—recorders, controllers, panelboards, valves and all accessories.*

Call in our local engineering representative for a detailed discussion of your process requirements . . . he is as near as your phone. Offices in more than 80 principal cities of the United States, Canada and throughout the world.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4427 Wayne Ave., Philadelphia 44, Pa.

MINNEAPOLIS **Honeywell**

BROWN INSTRUMENTS

COLUMBUS MEETING

(*Continued from page 20*)

Members of the Public Relations Committee at Columbus breakfast meeting.

their early appearance in Chemical Engineering Progress.

The Committee on Judging the presentation of papers headed by Prof. Donald L. Katz of the University of Michigan, said that for this meeting the honor was divided between two men. Prof. J. A. Gerster, University of Delaware, for his presentation of the paper "Fundamental Factors Affecting Mass-Transfer Rates on Bubble Plates," and Prof. W. R. Marshall, Jr., University of Wisconsin, for his presentation of the paper, "An Electronic Drop-Size-Distribution Analyzer." The judging of papers by the Institute is done to encourage members to make better presentation of their work. The certificates of award are usually given to the winners at a meeting of their local section.

NEWS

(*Continued from page 25*)

NAT. LEAD LEASES BASIC MAGNESIUM PLANT

National Lead Co. has leased several buildings at the Henderson (Nev.) site of Basic Magnesium Inc. and has contracted for power there with the Colorado River Commission of Nevada.

Production of titanium metal with these facilities is under consideration, but no decision on immediate steps has been reached. A plant capable of turning out large tonnages of the metal involves a cost of fifteen to twenty million dollars. Such an operation also requires several hundreds of millions of kilowatt hours of power annually.

The lease at present gives National Lead Co. 80 acres of land with seven buildings totalling almost 200,000 sq.ft. in area. Power allocations have already been made to the extent of 151 million kilowatt hours annually.

Titanium metal has qualities of strength, light weight, corrosion resistance, and heat resistance which make it potentially important in military equipment. Production in large volume, however, depends upon creation of a large enough market at a relatively high price.

NEW SYNTHETIC FIBER FOR DU PONT

Du Pont will make a new synthetic fiber at a new plant to be located at Kinston, N. C. The new synthetic textile fiber known tentatively as Fiber V, is a condensation polymer obtained from ethylene glycol and terephthalic acid. It is not chemically related to nylon.

The Du Pont Co. said that the site had been purchased for a nylon plant but the change in plans was dictated by several factors. First, extensive market studies have led to the conclusion that Fiber V should be put in commercial production as soon as possible. Second, it was decided that the additional nylon yarn capacity, planned originally for the Kinston project, can best be provided, under the present construction materials situation, through technological improvements in production facilities and expansion at existing nylon yarn plants at Seaford, Del., Martinsville, Va., and Chattanooga, Tenn.

Design of the plant for Fiber V is under way and construction is expected to start sometime this year.

GOVERNMENT'S PLANT AT INSTITUTE REACTIVATED

Reactivation of the government synthetic rubber plant at Institute, W. Va., by B. F. Goodrich Chemical Co. is well into the "check, clean—and recondition" stage according to Tom B. Nantz, plant manager.

In stand-by since 1947, the Institute *GR-S* plant is undergoing complete "face-lifting" with valves, tanks, piping, condensers and motors being torn down, cleaned, inspected, replaced wherever necessary and reassembled. A modernization program is running concurrently, so that various process improvements made in the production of *GR-S* rubber during the last three years can be incorporated.

B. F. Goodrich Chemical Co., the new plant operators, took over from U. S. Rubber Co., Nov. 1, following notification from Reconstruction Finance Corp. that it would operate the copolymer plant in the new government rubber program.

The Institute copolymer plant is constructed in units of 30,000 long tons, each with its own pigment preparation, polymerization, recovery and finishing operations. Referred to as *A*, *B* and *C* "lines" these individual production units will not all begin operating at once, Nantz said. "It is our hope to have our first production line working by Jan. 1, and remaining lines in by March."

MANPOWER PLANS SUBMITTED TO N.S.R.B.

THE emergency in America's scientific manpower, present and pending, has recently caused scientific and engineering organizations to foster numerous plans for the efficient use of technical personnel. Last month the Engineering Manpower Commission of the Engineers' Joint Council proposed to the National Security Resources Board the establishment of a National Engineering Personnel Board to make selections for military, civil defense or industrial allocation from a reserve of men, up to age 70, with training in one of the critical fields of engineering.

The Engineering Manpower Commission of the Engineers' Joint Council said that the reserve should be created through registration by selective service of every man up to 70 who has a bachelor's degree with a major in a critical field of engineering or who was enrolled in a college course leading to such a degree, or who was employed in these fields. The proposals were submitted to R. L. Clark, Director of the Manpower Office of the National Security Resources Board. The plan was formulated as part of a task given the E.J.C. in September by Mr. Clark, to prepare "a program for the most effective utilization of engineers in the national effort."

The American Institute of Chemical Engineers is represented on the 20-member Manpower Commission of the E.J.C. by W. I. Burt of the B. F. Goodrich Chemical Co., Cleveland, Ohio, F. J. Curtis of the Monsanto Chemical Co., St. Louis, Mo., and C. G. Kirkbride of the Houdry Process Corp., Marcus Hook, Pa. S. L. Tyler, Secretary of the Institute, is also a member of the Commission, as well as being an adviser to the director of Selective Service, as a member of the Engineering and Sciences Committee.

The basic purpose of the engineering reserve, said the Commission, is "so to earmark specialized skills needed that a prestige will be accorded to its members that may offset the emotional desire of the young man to enlist rather than devote his efforts to the work for which he is best fitted."

Regarding the Conant Plan for Universal Military Service, the Commission said it recognized the desirability of the universality of obligation for service in some essential form by the entire citizenry. The Commission believes, however, that any such plan as the Conant Plan must be modified to recognize the following principles:

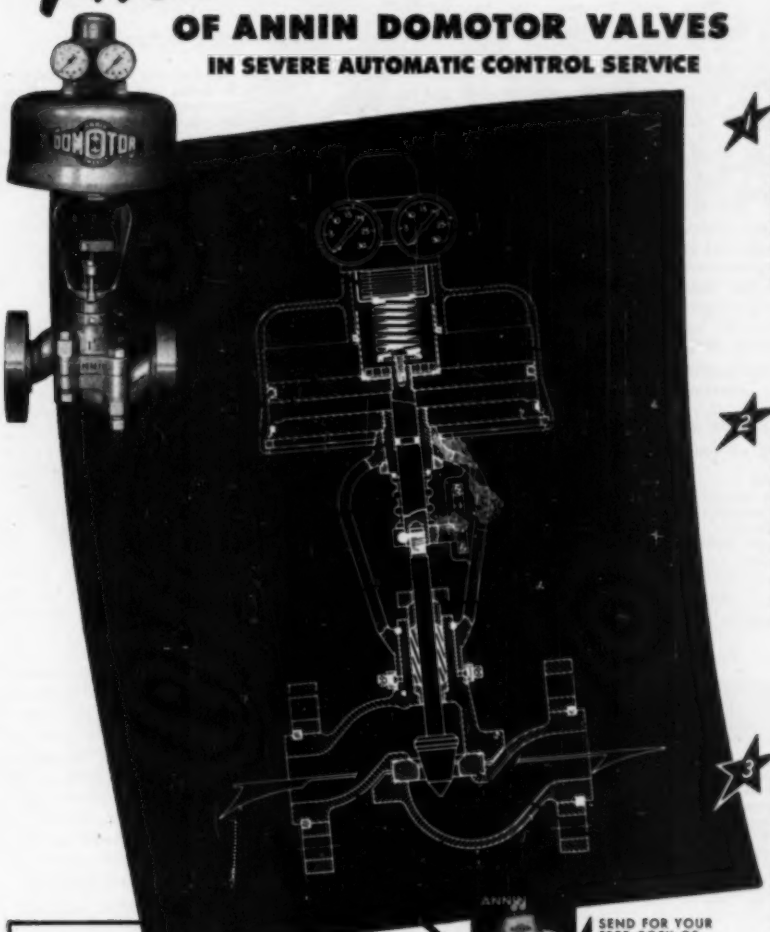
"1. The fundamental policy of continuing training of qualified scientific, technical, and engineering personnel,

(*Continued on page 34*)

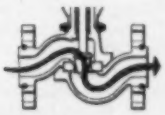
4 REASONS FOR THE *Phenomenal Acceptance*

OF ANNIN DOMOTOR VALVES

IN SEVERE AUTOMATIC CONTROL SERVICE



1 POSITIVE AUTOMATIC OPERATION. Powerful Domotor unit with built-in valve positioner and sealed-in piston . . . replacing conventional spring and diaphragm with externally attached positioner . . . is not limited to lower operating pressures or short valve travel. Simple, practical design provides a stability and precision of operation not found in other control valves.



2 PROVEN SINGLE SEAT VALVE BODY DESIGN. Valve seat is clamped in position between separable body valves permitting a smooth, clean, non-turbulent flow passage that effectively handles slurries, sludges, and viscous fluids at high pressures and temperatures. Pressure drop is minimized. Unique construction allows economical manufacture in a wide range of alloys.

3 DEPENDABLE SERVICE UNDER ADVERSE CONDITIONS. Domotor assembly actuating the one-piece stem and valve plug within the simplified valve body provides the surest combination for dependable service. Development of the Annico Seat Seal permits use of Telfon and other wear-resistant seating surfaces to insure bubble-tight shut-off, even under the *most* corrosive conditions.

4 LOW MAINTENANCE COSTS. On the job, in the line, replacement of valve plug, ring seat and other vital parts is rapidly completed. Grinding-in operations are eliminated due to inherent seat alignment. Interchangeable line flanges permit use of one valve anywhere in plant regardless of line pressure, further reducing inventory and operating costs.

PARTIAL [illegible] OF SATISFIED USERS OF ANNIN DOMOTOR VALVES

Cities Service Refining Co.	Carbide & Carbon Chemicals
Gulf Oil Corp.	Celanese Corporation of America
Humble Oil & Refining Co.	Corn Products Refining Company
Magnolia Petroleum Co.	The Dow Chemical Company
Pure Oil Co.	E. I. du Pont de Nemours & Co.
Shell Oil Co.	Ethyl Corporation
Sinclair Refining Co.	Jefferson Chemical
Standard Oil Co.	Mathieson Alkali
Superior Oil Co.	Monsanto Chemical Co.
Texas Oil Co.	Pittsburg Coal & Chemical

SEND FOR YOUR FREE COPY OF THIS BULLETIN . . . describing the features of this outstanding line of Valves. *Write* now!

Investigate

ANNIN DOMOTOR VALVES *Valves*

THE ANNIN COMPANY

3500 Union Pacific Avenue, Los Angeles 23, California

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Valuable Listing in One Volume

Industrial Chemicals. W. L. Faith, Donald B. Keyes, and Ronald L. Clark. John Wiley & Sons, Inc., New York. (1950) 652 pp. $8.00.

Reviewed by L. H. Allen, Jr., R. A. Sandler, and R. O. Wolff, Foster D. Snell, Inc., New York.

IN THEIR preface the authors' stated aim in the preparation of this text is "The compilation in a single volume of important technical and economic data concerning the major industrial chemicals." The 106 chemicals covered by this text are manufactured wholly or in part either by synthetic or biochemical methods and are presently, or expected to be, of major industrial importance. The information has been compiled in accordance with the following outline:

1. Name and chemical formula.
2. Manufacturing processes in current use, including simplified flow sheets and important process variables.
3. Equations for the principal reactions involved; average yield expectation in per cent of theoretical.
4. Raw material requirements per unit weight of commercial product. In some cases, utility and labor requirements are shown.
5. Production chart for past 20 years.
6. Generalized use pattern.
7. Price chart for past 20 years.
8. Miscellaneous data, including physical properties, commercial grades, shipping regulations, and usual containers.
9. Economic aspects, generally including historical data, a discussion of competitive processes and products, recent trends in manufacturing and sales, actual and economic plant size, and approximate plant cost (as of 1946).
10. A map showing the location of manufacturing facilities in the United States.

This text brings together extremely valuable manufacturing, plant cost and production cost data on a variety of important industrial chemicals and should prove of value to the chemical process and design engineer, and to those concerned with sales and management in the chemical industry. The presentation is concise and the standardized arrangement makes for ease in locating specific information. Of special interest is the information presented on the various product grades manufactured, shipping containers and shipping regulations. Process flow sheets and process descriptions are sufficiently detailed to give the reader a reasonably thorough understanding of the major processing steps involved and the equipment requirements. Raw material requirements, yields and process variables are also discussed where such information has been available to the authors.

Although this text represents one of the most complete compilations of information of this type, omission of references to the sources of the data presented detracts somewhat from its usefulness. The authors also might have done well to present a list of the major producers of each chemical.

With the exception of these minor criticisms the authors are to be congratulated on the preparation of a valuable contribution to the literature of the chemical industry.

Heat Transfer and Pressure Drop

University of Delaware Engineering Experiment Station, Bulletin No. 2: Heat Transfer and Pressure Drop During Viscous Flow Across Unbaffled Tube Banks. Olaf P. Bergelin, Allan P. Colburn, and Harold L. Hull, University of Delaware, Newark, Del. (1950) 55 pp. $1.00.

IN this separate publication the University of Delaware has presented in complete form material partially published in the Transactions of the American Society of Mechanical Engineers. Additional data on the effect of the number of rows of tubes are included plus, of course, much more detailed information than the original articles contained. Restrictions on the length of the journal article in the *A.S.M.E.*, prevented presentation of all the experimental data and details of the equipment, and the authors felt that for the maximum of service to the profession, a separate publication of the complete article was in order.

The book is some 50 pages long and contains more than 15 pages of experimental data.

Editor's Note:

In the November, 1950, issue of *Chemical Engineering Progress*, page 39, we forgot to mention the fact that the book, "Chemical Engineering Reports," by Kenneth A. Kobe, is priced at $1.00. Orders should be sent to Hemphill's Bookstore, Austin, Tex.

Appraising and Economics

Chemical Engineering Cost Estimation. Robert S. Aries and Robert D. Newton. Chemonomics, Inc., New York. (1950) 109 pp. $5.00.

Reviewed by Chaplin Tyler, Development Department, Du Pont Co., Wilmington, Del.

THIS publication is largely a compilation of process equipment costs and related process cost data. Some three fifths of the approximately 100 pages is devoted to equipment costs, expressed in the form of 67 readily interpreted graphs. This topic is by far the most exhaustively treated part of the subject matter.

Other topics covered are Short Cut Methods of Estimation; Manufacturing Cost Estimate; Capital Investment Estimate; Return on Investment; Methods of Expressing Profits; and Break Even Charts. The first three of these topics seemed to the reviewer to be more clearly and carefully handled than the last three, which in places could benefit by greater precision in thought and expression. In general the subject matter is soundly treated and should assist in developing the needed more widespread skill in appraising the economics of chemical processes and products.

The reviewer would caution that so far no easy yet safe route to cost estimation has been devised. The responsible estimator, who must stand or fall with his results, still follows the time-tested path of orthodoxy; to develop each estimate from the ground up, using current quotations, reliable experience factors, plus his own good judgment.

Books Received

Gas Producers and Blast Furnaces. Theory and Methods of Calculation. Wilhelm Gumz. John Wiley & Sons, Inc., New York. (1950) 316 pp. $7.00.

Superfluids. Fritz London. Vol. 1. Macroscopic Theory of Superconductivity. John Wiley & Sons, Inc., New York. (1950) 161 pp. $5.00.

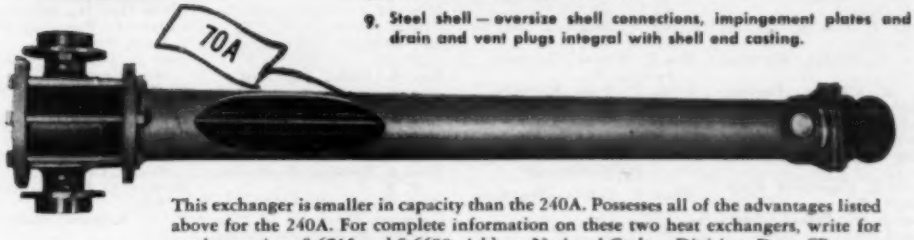
Analytical Chemistry of the Manhattan Project. C. J. Rodden, editor in chief. McGraw-Hill Book Co., Inc., New York. (1950) 748 pp. $6.75.

Industrial Plant Location—Its Application to Zinc Smelting. Carl H. Cotterill. American Zinc, Lead and Smelting Co., St. Louis, Mo. (1950) 155 pp. $5.00.

Here's the dope on 2 "KARBATE" IMPERVIOUS GRAPHITE HEAT EXCHANGERS

The new No. 240A is a shell-and-tube heat-exchanger made of "Karbate" brand impervious graphite... similar in construction to the familiar No. 70A... but with almost three times as much total effective external heat transfer surface. Advantages are:

1. 70.6 sq. ft. of external heat transfer surface.
2. Single, double or four-pass routing of tube-side fluid is effected by a simple change of fixed and floating end-cover assemblies.
3. Wide variety of corrosive fluids handled with negligible maintenance.
4. Thermal shock resistance.
5. Very high heat transfer rates.
6. Stainless steel baffles.
7. Easy tube replacement in the field.
8. Removable "Karbate" tube bundle.
9. Steel shell — oversize shell connections, impingement plates and drain and vent plugs integral with shell end casting.



This exchanger is smaller in capacity than the 240A. Possesses all of the advantages listed above for the 240A. For complete information on these two heat exchangers, write for catalog sections S-6715 and S-6690. Address National Carbon Division, Dept. CP.

A LITTLE PICK-ME-UP OF H_2SO_4 MAY HELP THAT INDIGESTION I'VE BEEN GETTING FROM 'KARBATE' IMPERVIOUS GRAPHITE

The terms "Karbate" and "Eveready" are registered trade-marks of

NATIONAL CARBON DIVISION
UNION CARBIDE AND CARBON CORPORATION
30 East 42nd Street, New York 17, N.Y.
District Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco
In Canada: National Carbon, Ltd., Toronto 4

SLASH BATTERY COSTS IN HALF

With the revolutionary new "Eveready" No. 1050 Flashlight Battery you get these big exclusive features:

- More than twice as much light.
- Whitest, brightest light available from a flashlight battery.
- Half the cost for light output.
- Leakproof—no metal can to leak or corrode.
- Will not swell, stick or jam in a flashlight.

Why? Because of the *exclusive* "inside-out" construction of the "Eveready" No. 1050 battery. Instead of being the container for the cell, the zinc electrode is on the inside to make the battery last longer, while the new outside carbon jacket makes the battery leakproof. Order a supply of No. 1050's *today*.

HEAT EXCHANGERS • PUMPS • VALVES • PIPING • TOWERS • TOWER PACKING • BUBBLE CAPS • BRICK • STRUCTURAL CARBON • SULPHURIC ACID CUTTERS • HYDROCHLORIC ACID ABSORBERS

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *Feb. 15, 1951*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Wm. Jack Anderson, *Kansas City, Mo.*
Leon L. Baral, *Baltimore, Md.*
Louis C. Bearer, *Bartlesville, Okla.*
Andrew Bela, *Lincoln Park, Mich.*
Charles G. Bragg, *Los Angeles, Calif.*
Wilson F. Brown, *Gainesville, Fla.*
James M. Carter, *Morovia, Calif.*
Leon R. Chrzan, *Detroit, Mich.*
Donald W. Collier, *Bridgeport, Pa.*
Burton V. Coplan, *Troy, N. Y.*
Vincent L. Crawford, *Pittsburgh, Pa.*
Clarence W. Fisher, *Pittsburgh, Pa.*
Wendell K. Fitch, *Springfield, Mass.*
Edward Greenfield, *Philadelphia, Pa.*
G. H. Gribbins, *Pittsburgh, Pa.*
Everett Harris, *Albany, Calif.*
Delbert L. Haynes, *Sandpoint, Idaho*
Robert R. James, *Front Royal, Va.*
Hugh L. Kellner, *Oakmont, Pa.*
M. R. Lents, *Houston, Tex.*
S. Philip Marcus, *Charleston, W. Va.*
Peter Michaelson, *Aldan, Pa.*
James W. Milne, *Libertyville, Ill.*
Louis W. Munchmeyer, *Binghamton, N. Y.*
A. Norman Pedersen, *Wilmington, Del.*
Robert W. Pressing, *Racine, Wis.*
Edward M. Redding, *Dayton, Ohio*
John R. Ruhoff, *St. Louis, Mo.*
A. Lyndale Schultz, *Avon Lake, Ohio*
Robert D. Sieg, *Argo, Ill.*
Judson J. Swift, *Brooklyn, N. Y.*
Alwin Tonkonogy, *Teaneck, N. J.*
C. E. Visclone, *Orange, N. J.*
Lloyd M. Watson, *Cincinnati, Ohio*
Roy F. Weston, *Newtown Square, Pa.*
Louis T. Yule, *Baytown, Tex.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Hugh F. Colvin, *Pasadena, Calif.*
Hugh M. Hulburt, *Washington, D. C.*
Horace Johnson, *Accrington, England*
Robert Curtis Johnson, *State College, Pa.*

APPLICANTS FOR JUNIOR MEMBERSHIP

James N. Ademino, *Villanova, Pa.*
Ralph R. Ashley, *Morgantown, W. Va.*
Frank C. Baginski, *New Haven, Conn.*
Albert J. Barnes, Jr., *Indianapolis, Ind.*
Roy M. Barnes, *Los Angeles, Calif.*
Reginald R. Baxter, *El Dorado, Ark.*
Patrick R. Black, *Houston, Tex.*
Z. D. Bonner, *Port Arthur, Tex.*
Paul J. Brooks, *Naugatuck, Conn.*
Phyllis M Brown, *Richland, Wash.*
Norman H. Callner, *Chicago, Ill.*
John E. Carlson, *New York, N. Y.*
Joseph D. Chachere, Jr., *Port Arthur, Tex.*
F. S. Chalmers, Jr., *Cartersville, Ga.*
Elwood K. Colbert, *Pittsburgh, Pa.*
Howard J. Craven, *Ketchikan, Alaska*
Leo DiRicco, *Pullman, Wash.*
Lou K. Dods, *Highland, Ind.*
William C. Duckworth, *Atlanta, Ga.*
William J. Evers, *Baton Rouge, La.*
Paul J. Fleming, *Rochester, N. Y.*
Alan K. Forsythe, *Lancaster, Pa.*
Chester H. Gelbert, *Penns Grove, N. J.*
Orlin J. Gibbs, *Port Arthur, Tex.*
Paul R. Haas, Jr., *St. Louis, Mo.*
Wm. Robert Harrington, *Bloomington, Ill.*
David Hellums, *Beaumont, Tex.*
Stuart T. Hodes, *Ashtabula, Ohio*
Herbert W. Hoffman, *Oak Ridge, Tenn.*
Pierre E. Holloway, *Port Arthur, Tex.*
Axel R. Johnson, *Pittsburgh, Pa.*
Ralph E. Johnson, *Richland, Wash.*
Sherman C. Justus, Jr., *Port Arthur, Tex.*
Gordon D. Kerns, *Marcus Hook, Pa.*
Lawrence Kuster, *Mineola, N. Y.*
Wallace W. Lees, *Hansdale, Ill.*
Franklin Miley, *Sand Springs, Okla.*
Robert Lewis Miller, *Terre Haute, Ind.*
Egon M. Muller, *Nitro, W. Va.*
Marlin P. Nelson, *Marcus Hook, Pa.*
Robert F. Neu, *Philadelphia, Pa.*
William F. O'Brien, Jr., *Columbia, S. C.*
Clyde Orr, Jr., *Atlanta, Ga.*
Casper C. Paprocki, *Pottstown, Pa.*
John L. Pearson, *Arlington, Wash.*
P. Walter Pritchett, *Baton Rouge, La.*
William H. Prokop, *Argo, Ill.*
William H. Rader, *Baton Rouge, La.*
Stewart E. Rogers, *Benton, Ark.*
R. T. Romans, *Galveston, Tex.*
Robert S. Schechter, *Minneapolis, Minn.*
Leonard H. Silver, *Rahway, N. J.*
David M. Smith, Jr., *Port Arthur, Tex.*
R. W. Smyth, *Natrona, Pa.*
Erich Sokolower, *Beaver, Pa.*
Robert J. Spera, *Philadelphia, Pa.*
James J. Staikos, *Everett, Mass.*
Hans J. Treumann, *Louisville, Ky.*
Jack C. Troy, *Pittsburgh, Pa.*
Stanley Tucker, *Collingdale, Pa.*
Alfred F. Werner, *Allentown, Pa.*
Robert A. Williamson, *Knoxville, Tenn.*
Ira A. Wolfson, *Penns Grove, N. J.*
Edward D. Wurster, *El Dorado, Ark.*

SOLID PORCELAIN

Lapp

PORCELAIN VALVE

● Valves of Lapp Chemical Porcelain are known in the chemical processing industry as the most effective for handling many corrosive chemicals. And *porcelain* is the body material itself, not a paint or enamel. The porcelain is dense, homogeneous, *non-porous, through-and-through* acid resisting. Not even is the corrosion resistance of this material due to a glaze. In fact, the smooth operation and pressure-tight seal is the result of machining—grinding and lapping the solid porcelain—which is finished to an accurate, mirror-like smoothness.

In many points in the chemical industry, Lapp valves have been found the only satisfactory answer to the problem of handling corrosive chemicals. Perhaps they can save trouble for you, too. Lapp Insulator Co., Inc., Process Equipment Division, 406 Maple St., LeRoy, N.Y.

Lapp

PROCESS EQUIPMENT

CHEMICAL PORCELAIN VALVES • PIPE • RASCHIG RINGS

PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

CHEMICAL PORCELAIN BULLETIN NOW AVAILABLE

Chemical and mechanical characteristics of Lapp Porcelain; specifications and dimensions for valves, pipe, raschig rings, towers; installation procedure and maintenance hints. Write for your copy.

from paint

to potato chips!

process men value

DOWTHERM

The heat transfer medium for high temperatures

Yes, in addition to its economy, simplicity, and efficiency, Dowtherm is safer!

Dowtherm permits the use of a system in which the fire is removed from any flammable material in process. High-temperature operations, formerly possible only under dangerous and costly conditions, are now accurately and safely controlled by this indirect system. Dowtherm presents little hazard in handling, in shipping and storage.

Today Dowtherm users, whether they be paint manufacturers or food processors—or engaged in any other high-temperature operation—enjoy a security unknown in earlier systems. If your operations require precise heating in the 300°—750° F. range, write to Dow for complete information about Dowtherm.

THE DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

THE DOW CHEMICAL COMPANY
DEPT. DO-4
MIDLAND, MICH.

Name_____ Title_____

Company_____

Address_____

City_____ State_____

DOW
CHEMICALS
INDISPENSABLE TO INDUSTRY AND AGRICULTURE

MANPOWER PLANS

(*Continued from page 28*)

needed in the years ahead, in the interest of national security, health and welfare.

2. The fundamental policy of providing for both the military and industrial needs for scientific, technical and engineering personnel."

The Commission emphasized that a "fundamental and essential condition of any program of defense depends on realization that the survival of the United States as a free democracy in the world-wide struggle for control will depend on 'superior and prior scientific and engineering skills to offset superiority of numbers which the free nations lack."

The American Chemical Society a week later called for essentially the same total mobilization of the scientific and technical manpower except the ages were between 18 and 65. The chemists' all-out mobilization plan, which would transfer control over scientific manpower from Selective Service to a new civilian board, would become effective only in a situation so grave as to compel adoption of a national service act—at least for technical personnel.

For the present, the A.C.S. report said, optimum utilization of scientific and engineering skills within the terms of existing legislation should be sought through the modification in procedure suggested to Major General Lewis B. Hershey, Director of Selective Service, by his scientific advisory committees. The central proposal of these committees is that superior university students be deferred from military service indefinitely to continue their studies, and even longer if their training and capabilities are needed elsewhere in the defense program.

The report was transmitted by Dr. Charles Allen Thomas of St. Louis, chairman of the Society's board of directors, to Robert L. Clark, Director of the Manpower Office of the National Security Resources Board. Mr. Clark had requested the A.C.S. also for a plan for the effective use of trained men in times of emergency.

The A.C.S.'s plan said that in a large-scale mobilization program, individuals having special skills should be made available to the armed services only on military requisition showing need for such persons with specific training and experience. The chemists gave three reasons for this belief

"1. In an all-out war, the United States and its allies would be outnumbered and our chance of success would be based upon our capacity to produce more and better weapons than the enemy.

2. The United States must plan on maintaining superiority in weapons over an extended period of time, which will require continued technical developments.

3. The total number of individuals in the United States possessing critical skills is a relatively small proportion of our total manpower."

The third Manpower Plan during the month came from Dr. Henry DeWolf Smyth of the Atomic Energy Commission during an address to the American Association for the Advancement of Science, meeting in Cleveland for its 117th Annual Meeting. Smyth proposed the establishment of a scientific service corps directed by a Scientific Manpower Board. Smyth said that a mere outpouring of men could not beat our enemies. They could only be defeated by "our being much brighter, much sharper, much more cold and more far-sighted than they." He suggested stockpiling and rationing scientific men much as we would any other essential commodity.

However, Dr. Smyth's corps contained only scientists who had done graduate work in natural and physical sciences which left the engineer out of the picture. He also proposed a student corps to take care of the training problem for scientists. The Board, he said, should be responsible to the President and not to the Department of Defense.

COMPANIES QUESTIONED ON MANPOWER USE

E. G. Bailey, chairman of the Engineering Manpower Commission of the Engineers' Joint Council, of which the American Institute of Chemical Engineers is a member, revealed to *Chemical Engineering Progress* in time for this issue that on Dec. 29 he sent the following telegram to 90 different companies that might be affected by shortages of trained engineers:

"On behalf of engineering profession and in interest of effective emergency use of manpower request response to the following questions . . .

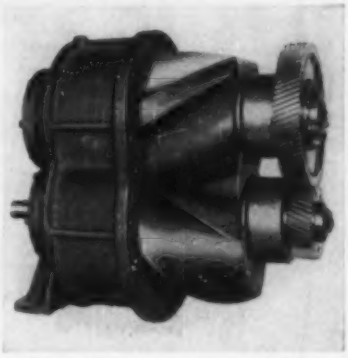
1. In your organization how many engineers and scientists at professional level, bachelor's degree or equivalent and higher and doing engineering or scientific work?
2. What is total number of such engineers in Armed Forces Reserve Status, both active and inactive?"

The information obtained will be used in the study which is now in progress of the over-all situation in order that constructive and reasonable suggestions may be made. See page 28 of this issue.

(*Continued on page* 48)

STANDARDAIRE

Precision Built Axial Flow



BLOWERS handle the movement of air gently by screw action instead of paddle action, as is the case with other positive displacement blowers. Result—air pulsations and noise are reduced to a surprisingly low level. In Standardaire Blowers the revolutionary new form of the rotors marks a major improvement in blower design. The rotors are produced by an exclusive rotary generating process, the form and helix being controlled entirely by the machine gears. This produces rotor threads that are accurately shaped and machined to close tolerances for efficient blower operation. The design of the rotors and other construction details makes possible internal compression to a degree that Standardaire Blowers operate on a modified adiabatic cycle with a lower mean internal pressure. This important feature, together with advanced engineering throughout, makes for a quiet, compact, efficient blower with long service life.

Write for Standardaire Blower Bulletin covering dimensional information. Publication No. 88.

The Standard Stoker Company, Inc., Dept. C-2, 370 Lexington Ave. New York 17, New York

Standardaire Blower equipped with unique pulley attachment for belt drive, when required.

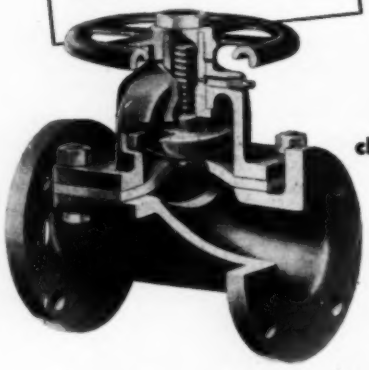
THE STANDARD STOKER CO • INC •

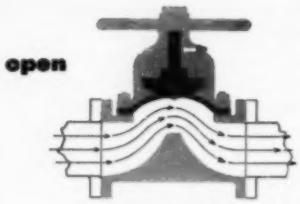
Standard Stoker SSC

NEW YORK • CHICAGO • ERIE • MONTREAL

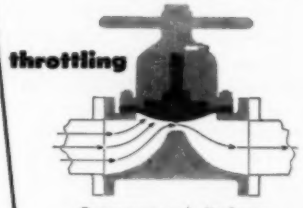
This Simple Principle

makes HILLS-McCANNA diaphragm valves unexcelled for handling corrosive materials, slurries and semi-solids

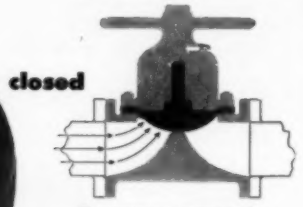




Compressor is raised, lifting diaphragm by means of a stud molded into the material.



Compressor and diaphgram partially lowered. Compressor design guides and supports diaphragm.



Compressor presses diaphragm tightly against weir pinching off flow and making a tight seal.

• When it comes to valving hard-to-handle fluids, the simple pinch clamp principle of Hills-McCanna valves (see above) eliminates most ordinary valve troubles. There is no leakage, no packing and material handled cannot contaminate or be contaminated by the working parts. Hills-McCanna Saunders patent diaphragm valves are the answer to many of the most serious valve problems. Write for full details and ask for a copy of Catalog V-48. HILLS-McCANNA CO. 2438 W. Nelson Street, Chicago 18, Illinois.

FOR 66° Bé SULPHURIC
Hills-McCanna now offers new plastic diaphragms for handling 66° Bé sulphuric. Write for details.

HILLS-McCANNA
saunders patent
diaphragm valves
Also manufacturers of Proportioning Pumps
Force Feed Lubricators • Magnesium Alloy Castings

LOCAL SECTION NEWS

BOSTON

At the Dec. 1, 1950, meeting, Joseph Pursglove, Jr., vice-president, research and development department, Pittsburgh Consolidation Coal Co., as guest speaker told of his extensive experiences in the coal industry. He covered problems basic to the production of coal at low cost and under satisfactory working conditions, also the technological advances that can be expected to take place on a large commercial scale in the next two or three years.

At the previous meeting R. M. Kimball, executive assistant to President Killian, M.I.T., discussed his experiences as associate director of the Los Alamos Scientific Laboratory in New Mexico.

Reported by Henry Avery

EL DORADO CHEMICAL ENGINEERS' CLUB

The final meeting for 1951 was held in El Dorado, Ark., Dec. 15; 38 members and guests were in attendance. The speaker for the evening was W. C. Alley, Arkansas Power and Light Co., who discussed "The Generation and Distribution of Electric Power in Arkansas."

Officers for 1951 were announced as follows:

Chmn.—C. H. Davenport (re-elected), Lion Oil Co., research div., El Dorado, Ark.
Vice-Chmn.—W. W. Chew, Louisiana Polytechnic Inst., Ruston, La.
Sec.-Treas.—A. A. Feerick, Lion Oil Co., research div., El Dorado, Ark.

At its Nov. 23 dinner meeting, held in the Garrett Hotel in El Dorado, Ark., 39 members and guests of the Club were addressed by A. M. Sprague, superintendent of the chemical division, Lion Oil Co. Mr. Sprague's subject was "Synthetic Nitrogen Fixation."

Mr. Sprague traced the development of the various processes devised to make nitrogen from the air available for use by mankind.

Reported by E. D. Wurster

LOUISVILLE

This section held a joint meeting with the American Society of Mechanical Engineers, Jan. 11, in the Speed Scientific School Auditorium. Frank Wilson, chief engineer, valves and fittings division, Henry Vogt Machine Co., spoke on "High Pressure Design Technique."

At the Dec. 12 meeting Albert Milnes, technical director, Sarco Co., New York, spoke on "Steam Trapping and Air

Venting." He showed how proper practice can result in improved capacity from many types of chemical processing equipment or reduce steam requirements.

At this meeting the following officers were elected for 1951:

Chairman-elect.....H. P. Hansen
Sec.-Treas......T. R. Linak
Exec. Comm......W. R. Barnes
H. L. Greene

Reported by W. B. Altsheler

EAST TENNESSEE

The 27th general meeting was held Dec. 12, 1950, at the Foremen's Room, Recreation Building (Building 89), Tennessee Eastman Corp., Kingsport, Tenn. Approximately 25 members and guests were present. A. A. Ringland, Raybestos-Manhattan, Inc., Birmingham, Ala., talked on "Pump Packings."

The following officers were elected for 1951:

Chmn. .....R. H. Morrison, Jr.
Vice-Chmn .....R. J. Schrader
Sec.-Treas. .....J. K. Pannill
Director .....H. A. Scott

Reported by R. H. Morrison, Jr.

KNOXVILLE-OAK RIDGE

This section continued the seminar series for 1950 with three topics presented during the fall as follows:

R. V. Bailey of the University of Mississippi spoke on heat transfer at entrance regions. Dr. Bailey considered the analytical treatment of both thermal and hydrodynamic effects.

H. F. Poppendiek, formerly with the University of California and now located at Oak Ridge National Laboratory, presented a discussion on atmospheric diffusion. Dr. Poppendiek pointed out that this field is receiving increased attention and offers many opportunities for advanced engineering analysis. Principal cases considered were diffusion of mass, as in air pollution or radiation contamination; and, diffusion of heat, as in diurnal changes.

Richard Stephenson of Oak Ridge National Laboratory concluded the seminars for the year with a study of continuous ion exchange. Dr. Stephenson discussed a multistage operation which typified action in a continuous two-component system.

Reported by W. B. Harrison III

DETROIT JUNIOR GROUP

H. P. Munger of the Battelle Memorial Institute, Columbus, Ohio, was the speaker at the Nov. 29 meeting in the Rackham Memorial Building. Dr. Munger discussed air pollution, sampling procedures and equipment for measuring air pollution, and preventive measures.

Reported by W. W. Jones

HIGH FLOW RATES WITH SPARKLER FILTERS

. . . frequently two to five times as high as the flow through filter septa lying in a different plane.

In Sparkler filters, friction encountered in high flow and high viscosity operations is reduced to a negligible factor by the free drainage and uniformity of cake provided by Sparkler's horizontal plate construction. Less operating pressure is needed, with the result that the cake is less dense and thus offers less resistance to flow.

Sparkler horizontal plates permit filter media to be floated into position forming a cake of uniform thickness. Only a thin precoat cake is necessary to assure brilliant clarity of the filtrate right from the start. This means maximum economy of pre-coat material and precoating recirculating time.

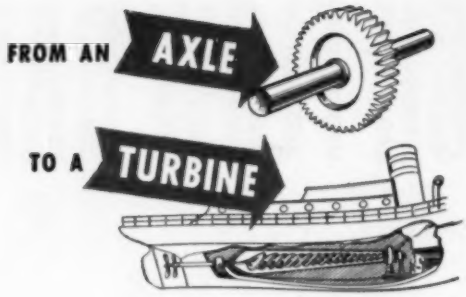
Section of filter plate showing perforated metal screen, filter media, and filter cake.

Cutaway view of filter plates showing how cake of uniform thickness is built up on each plate.

Write Mr. Eric Anderson for personal engineering service on your filtering problem.

Makers of filters for the Chemical, Pharmaceutical, Food and Petroleum Industries for over a quarter of a century

SPARKLER MANUFACTURING COMPANY Mundelein, Ill.



WHEREVER PETROLEUM IS USED AS LUBRICANT OR FUEL

ADSORBENTS

have helped to prepare it!

From plain axle grease to the most highly refined and specialized motor oils—

From the most common commercial grade of fuel to aviation gasoline of the highest rating—

New sense is given to the old saying that "oil and water don't mix."

Wherever decolorization or dehydration enters into petroleum processing, Floridin products have been approved for forty years.

If you have use for natural adsorbents in any industrial process, these products should be of interest to you.

FLOREX FULLERS EARTH

High-pressure extrusion insures maximum effectiveness.

BAUXITE-BASED ADSORBENTS

Write for full data. The advice of a competent technical staff is offered. Your inquiry will get prompt attention.

FLORIDIN COMPANY

Adsorbents . . . Desiccants . . . Diluents

Dept. O, 220 Liberty St., Warren, Pa.

NEW ORLEANS

At the meeting of this section held Dec. 7, 1950 the following officers were elected:

Chairman .....E. Fred Pollard
Vice-Chairman P. Leon Godchaux II
Secretary-Treasurer,
Kenneth M. Decossas
Active Member, Exec. Comm.,
Henri Jean Molaison
Member, Exec. Comm.,
Francis M. Taylor
Member, Exec. Comm.,
Angelo V. Graci, Jr.

John Halbig, research engineer, Armco Steel Corp., speaker of the evening, talked on five new stainless steels.

Reported by Ralph M. Persell

CHICAGO

Members of this section gathered again in the Western Society of Engineers' lounge and heard F. W. Klayer, manager of products research for Jos. E. Seagram & Sons, speak on "Quality Control." His talk dealt with a type of process control quite different from conventional chemical engineering practices. Mr. Klayer described the development of a control procedure involving the training of previously unskilled personnel to make accurate taste and odor choices so as to achieve a high degree of product uniformity. Both comparison and threshold techniques were described, and the method for establishing preference standards was told. In addition to Seagram's main concern with whiskey production, consulting studies for coffee, cigarettes, and other products involving taste and odor discrimination were discussed.

The program for Feb. 21, 1951, will include a talk on the manufacture of pharmaceuticals.

On Nov. 15 W. R. Marshall, professor of chemical engineering at the University of Wisconsin, spoke on "Atomization."

Reported by Thorpe Dresser

LOCAL SECTION CALENDAR

CHARLESTON SECTION: *Jan. 23, Charleston Recreation Center. Subject—"The Economic Position of the Coal Industry."*

OHIO VALLEY SECTION: *Jan. 31, Herman Schneider Foundation Building, Cincinnati. Joint Meeting with the American Chemical Society. Subject—"Chemical Engineering Symposium." Feb. 21, Inspection trip to Armco Steel Corp., Hamilton, Ohio.*

PITTSBURGH SECTION: *Feb. 7, Mellon Institute Auditorium. Speaker,* C. C. LONG, ST. JOSEPH LEAD CO. *Group discussion led by selected section members in the fields of production, research, design and sales.*

AKRON

A meeting of this section was held at the University Club, Dec. 12, 1950. About 60 members and guests attended.

Officers for 1951 were elected as follows:

Chmn......Robert C. Stell
Vice-Chmn......John W. Kosko
Sec......Edmund Duplaga
Treas......William Harlacher

Guy N. Harcourt, vice-president engineering, Buflovak equipment division, Blaw-Knox Co., spoke to the group on Atmospheric and Vacuum Drum Dryers. Atmospheric drum dryers, he said, are used to dry materials which occur in the form of liquids or slurries. Their uses have expanded until now an enormous variety of materials is dried on them, ranging from stillage to pharmaceuticals and including dyes, gelatinized starch, soap, etc. In addition to a description of design details, operating data taken from plant-scale installations were presented.

Reported by John W. Kosko

NORTHERN CALIFORNIA

The meeting of Dec. 4 held at the Engineers Club in San Francisco had 90 in attendance. Following the dinner the group heard an address, "Management and the Engineer," by Howard Vesper, president of California Research Corp.

Including chemists and physicists under a broad definition of "engineer" the speaker stressed the importance of all-round education, as well as technical training, if men are to make the most of their opportunities and at the same time become most helpful to management. Technologists should continue, after leaving school and entering industry, to widen their interests, said Vesper, who added that participation in community affairs is one of the best means of keeping the engineer from sinking into a rut.

Reported by J. V. Hightower

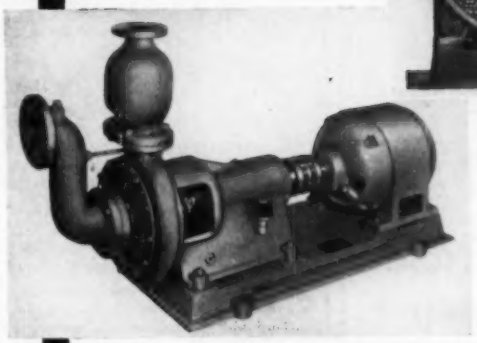
WASHINGTON-OREGON

Officers for 1951 are as below:

Chmn.—F. B. West, dept. of chem. and chem. eng., University of Washington, Seattle 5, Wash.
Vice-Chmn.—W. S. Munro, Monsanto Chemical Co., Western div., 911 Western Avenue, Seattle 4, Wash.
Sec.-Treas.—B. B. Butler, The Borden Co., chem. div., 6010 Airport Way, Seattle 8, Wash.
Exec. Comm.—N. F. Robertson, West Tacoma Newsprint Co., West Tacoma, Wash.; F. R. Armbruster, Dow Chemical Co., Textile Tower, Seattle 1, Wash.

Reported by W. S. Munro

(Right) Lawrence Self-Priming Pump exhausting air during priming.



(Left) Lawrence Heavy Duty Self-Priming Chemical Pump.

LAWRENCE... SELF-PRIMING PUMPS

Patent Applied For

A new type for many exacting services

This is *the first real self-priming centrifugal pump ever invented:* — specifically, a pump that operates as a positive air pump during priming and then as a regular centrifugal pump. No valves of any kind are required. After priming, it operates — without recirculation of the liquid— at full efficiency.

Because dead spaces are eliminated and clearances are not close, the pump can be used for pumping liquids containing solids and abrasive matter in suspension. It can be furnished in all sizes for all classes of service: — water, slurry, sludge, acids and chemicals.

For further information and performance data, write for Bulletin 210-1.

LAWRENCE PUMPS

LAWRENCE
MACHINE & PUMP CORPORATION
375 MARKET STREET, LAWRENCE, MASS.

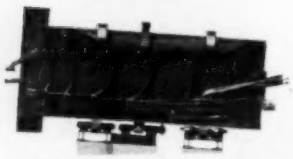
If your problem is

SEPARATING

Consult

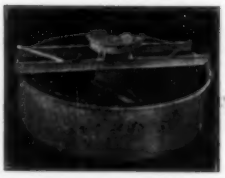
HARDINGE

COUNTER-CURRENT CLASSIFIERS, HEAVY-MEDIA SEPARATORS



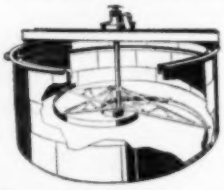
On the Iron Range, actual tests have proven the Hardinge Heavy Media Separator the most efficient of all types of separators. Extremely low maintenance requirements.

HYDRO-CLASSIFIERS



The "hindered settling sand cleaning zone" of this classifier produces an extremely clean underflow product. An adjustable weir permits variation in settling pool depth, which controls degree of separation.

HYDRO-SEPARATORS



Micron-size overflow product. Spiral scrapers clear the tank bottom of oversize in one revolution.

Write for Bulletin 39-B-40, covering complete line of wet classifiers.

HARDINGE
COMPANY, INCORPORATED
YORK, PENNSYLVANIA—240 Arch St. Main Office and Works
NEW YORK 17 • SAN FRANCISCO 11 • CHICAGO 6 • HIBBING, MINN. • TORONTO 1
122 E. 42nd St. 24 California St. 205 W. Wacker Dr. 2066 First Ave. 200 Bay St.

ST. LOUIS

This section met Nov. 21, 1950 at the York Hotel with 75 members and guests present.

J. G. Dobson, Foxboro Co., discussed "Cascaded Control Instruments." He discussed various applications of cascading for the chemical field and how to develop them; particular cases were described for fractionation columns and exothermic reactors.

The following were elected officers for the coming year:

Chmn.—Stan Lopata, Carboline Co.
Vice-Chmn.—Clyde Orr, Monsanto Chemical Co.
Sec.-Treas.—David Morris, Mallinckrodt Chemical Co.
Exec. Comm.—Ralph Whitson, Aluminum Ore Co.

Reported by R. S. Yates

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo
The M. W. Kellogg Co.,
225 Broadway, New York 7, N. Y.

MEETINGS

White Sulphur Springs, W. Va., The Greenbrier, March 11-14, 1951.
Technical Program Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.

Kansas City, Mo., Hotel President, May 13-16. 1951.
Technical Program Chairman: Walter W. Deschner, J. F. Pritchard Co., Kansas City, Mo.

Rochester, N. Y., Sheraton Hotel, Sept. 16-19. 1951.
Technical Program Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Annual—Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.
Technical Program Chairman: Frank J. Smith, Pan American Corp., New York, N. Y.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.
Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

SYMPOSIA

Relationship Between Pilot-Scale and Commercial Chemical Engineering Equipment
Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.
Meeting—White Sulphur Springs, W. Va.

Maintenance
Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Rochester, N. Y.

Industrial Applications of Photography
Chairman: Carl Gath, Eastman Kodak Co., Kodak Park Works, Rochester, N. Y.
Meeting—Rochester, N. Y.

Vacuum Engineering
Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

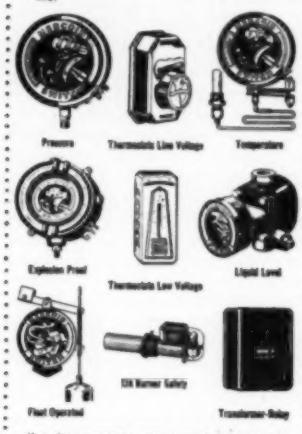
Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

MERCOID

SOLVES INDUSTRY'S AUTOMATIC CONTROL PROBLEMS

THE ONLY 100% MERCURY SWITCH EQUIPPED CONTROLS

The distinguishing feature of Mercoid Controls is the exclusive use of Mercoid hermetically sealed mercury switches. These switches are not subject to dust, dirt or corrosion, thereby assuring better performance and longer control life.



If you have a control problem involving the automatic control of pressure, temperature, liquid level, mechanical operations, etc., it will pay you to consult Mercoid's engineering staff—always at your service.

Complete Mercoid Catalog sent upon request.

THE MERCOID CORPORATION, 4201 BELMONT AVE., CHICAGO 41, ILL.

BIND

12

COMPLETE

ISSUES

for

$2.75

Never thicker than its contents, this binder expands to hold 12 issues of *Chemical Engineering Progress*.

No drilling, no punching, does not mar magazines.

Available for all years, with *Chemical Engineering Progress*, volume number and year stamped in gold on the backbone.

Use coupon below for order

CHEMICAL ENGINEERING PROGRESS
120 E. 41st St.
New York 17, N. Y. 1/51

Gentlemen: Please send ..... binder(s), @ $2.75 each, for each of the following years: .. .. to:

Name .....

Address .....

City ..... Zone .....

State .....

COLUMBIA VALLEY

The section held its 1950 annual meeting in the form of a dinner and semi-formal dance, Dec. 8, at the Desert Inn Hotel in Richland. The dinner dance was held in celebration of the first anniversary of the recognition of the section as one of the local sections of A.I.Ch.E. About 40 couples were present at this event.

Next year's officers will be as follows:

Chairman .....C. E. Kent.
Vice-Chairman .....S. S. Jones.
Secretary-Treasurer.H. E. Hanthorn
Executive Comm. ....V. D. Donihee, W. M. Harty, G. Thayer, B. Weidenbaum

In addition to officers who will serve ex officio.

In a meeting held Nov. 14, also in Richland, the section heard an address by C. A. Bennett, assistant chief statistician, Hanford Works, General Electric Co., on the subject, "The Statistical Approach to Industrial Experimentation." Dr. Bennett emphasized that statistical techniques may be used in planning experiments to secure the maximum in results from the minimum number of experiments.

An announcement was made of the technical paper contest for members of the Columbia Valley Section who are Junior members (or eligible for Junior membership) of A.I.Ch.E. The contest is being conducted by a special Contest Committee, under the chairmanship of H. E. Hanthorn.

Reported by George Sege

CHARLESTON, W. VA.

A general meeting was held at the Charleston Recreation Center Nov. 21, 1950; 136 members and guests were present.

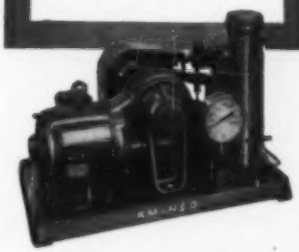
Chairman Stiles welcomed personnel from the Goodrich Rubber Co. who are activating the Institute West Virginia synthetic rubber plant belonging to the government.

The speaker of the evening was R. L. Dodge, manager of the Du Pont Co. polychemical department planning division. His subject was "Some Important Factors in Plant Location." Dr. Dodge opened his remarks by pointing out that despite considerable textbook material, plant site selection was a problem where practical knowledge and judgment were of great importance.

Dr. Dodge outlined such important, tangible and intangible factors as labor, fuel, raw materials, other chemicals, taxes, transportation, terrain, etc.

Reported by M. C. Guthrie, Jr.

HIGH PRESSURE
PUMPS
UP TO 30,000 PSI



Backed by
30 YEARS' EXPERIENCE

- **HYDRAULIC PUMPS**—Hand-operated and motor driven up to 30,000 psi.
- **HYDRAULIC PRESSURE INTENSIFIERS**—Up to 100,000 psi.
- **GAS COMPRESSORS**—Up to 15,000 psi.
- **GAS BOOSTER PUMPS**—Hand-operated and motor driven; up to 15,000 psi.
- **HYDRAULIC PRESSURE GENERATORS**—Up to 30,000 psi.
- **GAS CIRCULATORS**—Up to 6,000 psi.

Other Superpressure Products

REACTION VESSELS

FITTING & TUBING

PILOT PLANTS

INSTRUMENTS

VALVES

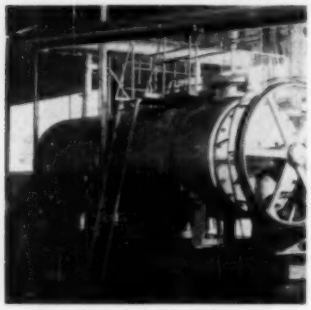
As pioneers—and still leaders—in the superpressure field, Aminco has an unmatched fund of experience which is at your disposal for the solution of your specific high-pressure problems.

Write for Catalog 406-E

Superpressure Division
AMERICAN INSTRUMENT CO.
Silver Spring, Maryland

25 YEARS OF TROUBLE-FREE DRYER OPERATION

(MAINTENANCE LESS THAN 10¢ PER DAY)



Standard-Hersey steam jacketed dryer built in 1925. All parts including bull gear are still functioning efficiently.

ANOTHER PROOF OF STANDARD-HERSEY *Dryer Economy*

Here is another case history proving why you are money ahead when you specify STANDARD-HERSEY dehydrating equipment.

This large steam jacketed dryer has actually cost its owners less than ten cents a day in maintenance—a total expense of only $750 for a full quarter century of exacting performance.

Other STANDARD-HERSEY dryers have even longer performance records of satisfactory service. STANDARD equipment is engineered and built to last. Over 30 different types of dryers are available for every process industry need.

STANDARD-HERSEY TEST DRYER

Let our "pilot" test dryer help determine how your product can best be dried. Duplicates performance under factory conditions of any type rotary dryer with any material.

WRITE TODAY FOR NEW DRYER BULLETIN

STANDARD HERSEY *Dryers*

STANDARD STEEL CORPORATION

8055 Boyle Avenue, Los Angeles 58, California
Eastern Address: 123–55 Newbury Street, Boston 16

SOUTHERN CALIFORNIA

A meeting was held Dec. 12, 1950, at the Rodger Young Auditorium in Los Angeles, at which some 115 members and guests were present.

F. A. Landee, associate professor, department of chemical engineering, University of Southern California, presented a paper on "Correlation and Prediction of the Physical Properties of the Liquid State." Dr. Landee discussed the physical picture of the liquid state with particular attention to boiling points, densities, vapor liquid equilibrium and azeotropes.

At this section's monthly dinner meeting Nov. 21, 1950, at Scully's Cafe in Los Angeles, 105 members and guests were present.

E. J. Kelly, sales manager, C. E. Howard Corp., was the guest speaker and his subject was "Frozen Orange Concentrate, Its Problems and Process." His discussion included the various aspects of the design, fabrication and operation of equipment used in preparing concentrated frozen orange juice, one of Southern California's growing industries. Of particular interest were the problems associated with equipment volume required for high vacuum operation, and the special needs associated with keeping full-scale process equipment in the sanitary condition required by the Food and Health laws.

Reported by William J. Baral

WESTERN MASSACHUSETTS

This section held its annual business meeting Dec. 14 and the following officers were elected:

Chmn. .....C. D. Smith (automatic)
Chmn-elect .....H. L. Minckler
Sec. .....J. E. Swan
Treas. .....G. Osterman
Exec. Comm.: E. T. Lindsey (two-year term); E. O. Ohsol (one-year term); C. A. Blaisdell (automatic succession from chairman)

At this meeting the section voted to participate in the March Science Exposition to be held at Technical High School in Springfield.

Reported by H. L. Minckler

PITTSBURGH

"Chemicals from the Sea" was the subject of an address by C. F. Prutton at the Dec. 6 dinner meeting, held at the College Club. Dr. Prutton, former head of chemical engineering at Case Institute of Technology, is now vice-president and director of operations, Mathieson Chemical Corp.

The speaker traced the growth of the chemical industry originally based on extraction of bromine from salt brines, founded and developed by the curiosity and personal drive of the late H. H. Dow. The modern processes carried on by the Dow Chemical Co. for extraction of minute amounts of bromine, iodine and magnesium from sea water and brines were reviewed by Dr. Prutton.

Reported by Hugh L. Kellner

PHILADELPHIA-WILMINGTON

This section met Nov. 14 at the Clubhouse Hotel, Chester, Pa., with 68 at dinner and 110 at the meeting.

L. L. Newman, gas engineer, fuels and explosives division, Bureau of Mines, spoke on "Trends in the Manufacture of Synthesis Gas."

The following officers were elected for the year 1951:

Chairman .....W. Herman Barcus
Vice-Chmn. .....A. P. Colburn
Exec. Comm. .....S. I. Winde
C. H. Brooks
S. David Ross
Corresponding Secy ...W. E. Osborn
Recording Secy .....Jack C. Dart
Treasurer .....R. B. Chillas, Jr.
Asst. Treas. .....W. A. Bours

Reported by R. B. Chillas, Jr.

NEWS

(*Continued from page* 35)

SLOAN GIVES M.I.T. FIVE MILLION

A gift of $5,250,000 from the Alfred P. Sloan Foundation, Inc., for the establishment of a School of Industrial Management at the Massachusetts Institute of Technology was announced last month by Dr. Karl T. Compton, chairman of the corporation of the Institute.

The concept of the school, he said, will be to correlate the complex problems of management in modern technical industry with science, engineering, and research. The objective will be to prepare young men of today better to meet the exacting demands of industrial management as they become the industrial executives of tomorrow.

BRITTON TO HEAD A.C.S.

Dr. Edgar C. Britton, director of the organic research laboratory of the Dow Chemical Co., Midland, Mich., has been chosen president-elect of the American Chemical Society. He will head the Society in 1952.

President for 1951 will be Dr. N. Howell Furman, Russell Wellman Moore, professor of chemistry in Princeton University, who took office Jan. 1, succeeding Dr. Ernest H. Volwiler, president of Abbott Laboratories, North Chicago, Ill.

PEOPLE

F. Dudley Chittenden was recently appointed factory manager of the Marvinol vinyl resin plant of the United States Rubber Co., at Painesville, Ohio. Formerly development manager of the Naugatuck chemical division, Dr. Chittenden joined U. S. Rubber in 1926 as a chemist in the company's general laboratories after receiving his Ph.D. in chemistry from Yale University. For next 16 years he worked in various capacities connected with chemical research and development, both in the general laboratories and in the company's Providence (R.I.) plant. Later he was transferred to the synthetic rubber division and in 1943 was named chief chemist of the Institute (W.Va.), synthetic rubber plant operated by Naugatuck Chemical for the U. S. Government. Subsequently he was named factory manager of the synthetic rubber plant in Naugatuck, Conn., and development manager of the Naugatuck chemical division. He holds numerous patents pertaining to the manufacture of rubber chemicals.

R. H. Boundy has been elected to the board of directors of The Dow Chemical Co., Midland, Mich. Dr. Boundy joined the Dow organization in 1926 following his graduation from Case and during his career with the company he has been especially active in the development and production of hydrocarbons and plastics. He became assistant director of physical research in 1930 and assistant to the president in 1941. Since 1945 he has been manager of Dow's plastics division, in which capacity he will continue to serve. Dr. Boundy is also a director of Dow Chemical of Canada, Ltd.

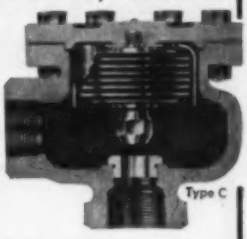
R. E. Florine has been appointed district manager and will be responsible for the sale of Whiting Corp.'s engineered products (cranes, foundry equipment and railroad equipment) in the states of Washington, Oregon and Idaho. He will handle also the sale of Swenson evaporators and chemical machinery. Mr. Florine is a graduate chemical engineer of Washington State College (1940). During the War he served for two years as engineering officer (Lt. E-USNR) aboard an escort carrier. For the past five years he has been a sales engineer in Whiting's district sales office in New York.

Nicholson Makes

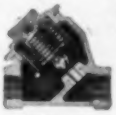
Freeze-Proof Steam Traps

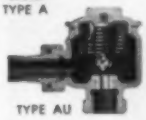
for Every Plant Use

Because they drain completely when cold, these four types of Nicholson steam traps are positively freeze-proof. Can be freely installed outdoors. Universally recommended for use in lines which need not be in continuous use during cold weather, because they are freeze-proof and because their 2 to 6 times average drainage capacity results in minimum heat-up time. The non-air-binding feature of Nicholson traps also notably facilitates steam transfer in severe weather.

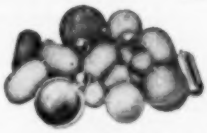


TYPE A


TYPE AHV


TYPE AU

Four types: size ¼" to 2"; press. to 225 lbs. BULLETIN 450.



HIGH-PRESSURE FLOATS—Stainless, monel, steel or plated steel. Welded. In all sizes and shapes; for operating mechanisms and as tanks or vessels. 2-day delivery. BULLETIN 650.

W. H. NICHOLSON & CO., 214 Oregon St., Wilkes-Barre, Pa.

BIN-LEVEL CONTROLS

2 BIN-DICATORS Often Replace 1 Man

BIN-FLO Aerating Units Keep Finely-Ground Materials Moving

ECONOMICAL MATERIAL CONTROL

DEPENDABLE BIN-LEVEL INDICATION

Mail this Coupon

THE BIN-DICATOR CO., 13946 Karcheval, Detroit 15, Mich.

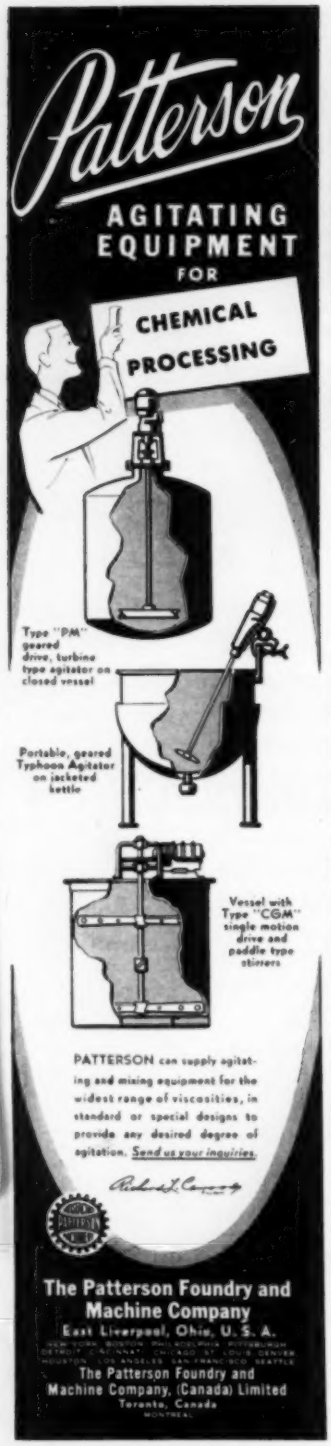
Please send new 20-page catalog giving complete information and specifications on BIN-DICATORS. Also please send information on BIN-FLO Aerating Units.

Name_____

Address_____

City_____ Zone____ State_____

CEP—1


Patterson
AGITATING EQUIPMENT FOR
CHEMICAL PROCESSING
Type "PM" geared drive, turbine type agitator on closed vessel
Portable, geared Typhoon Agitator on jacketed kettle
Vessel with Type "CGM" single motion drive and paddle type stirrers
PATTERSON can supply agitating and mixing equipment for the widest range of viscosities, in standard or special designs to provide any desired degree of agitation. Send us your inquiries.
The Patterson Foundry and Machine Company
East Liverpool, Ohio, U. S. A.
The Patterson Foundry and Machine Company, (Canada) Limited
Toronto, Canada

Paul S. Greer has been promoted to the position of manager of research and development, Office of Rubber Reserve, Reconstruction Finance Corp., Washington, D. C. For the past four years he served as assistant manager. Prior to entering Government service in 1942, he was with Carbide and Carbon Chemicals for 15 years.

William Resnick has accepted an appointment as head of the technological and chemical group of the scientific department of the State of Israel. For the six months prior to his leaving this country (he sailed Dec. 7) he was with the research department of the Standard Oil Co. (Ind.) in Whiting. Dr. Resnick completed his Ph.D. program at the University of Michigan in 1947 and was assistant professor of chemical engineering at the Illinois Institute of Technology in Chicago until 1950.

Philip S. Showell, who was associated with the Lubrizol Corp., Cleveland, Ohio, is now with the Arabian American Oil Co., Dhahran, Saudi Arabia.

Edward A. Schraishuhn, III, formerly assistant instructor of chemical engineering, University of Pennsylvania, is now process development engineer with Socony-Vacuum research and development.

Clifford C. Furnas, a director of A.I.Ch.E. (1945-47) and director of Cornell Aeronautical Laboratory, addressed the Cleveland Engineering Society session at the 117th meeting of the American Association for the Advancement of Science in the Cleveland Public Auditorium Dec. 27. His talk was entitled, "Partners in Research." The author of the Book of the Month Club selection, "The Next Hundred Years," has done research work for the Illinois Steel Co., U. S. Bureau of Mines and is the author of many technical articles.

Jose Serrano, Jr., recently formed a consulting engineering company, "Ingenieros Consultores Industriales S. A." with its main office in Aquiles Serdan No. 29, Mexico City. This company will assist growing Mexican industries in technical matters, will give advice on the kind of industrial plants to install and the best way to work with Mexican labor and Mexican conditions.

C. A. HOCHWALT ON EXEC. COMM. OF MONSANTO

Carroll A. Hochwalt has been appointed to Monsanto Chemical Co.'s executive committee. Dr. Hochwalt is a vice-president and a member of the board of directors. His sphere of activity will include the research, development and patent activities of the company.

Dr. Hochwalt was elected a member of the Board of Directors in March, 1949. He served as the first president of The Chemstrand Corp. and continues as a director of that company. He was director of the central research department from 1945-48. He has been with Monsanto since 1936, when the Thomas and Hochwalt Laboratories at Dayton, O., were acquired by Monsanto.

During World War II Dr. Hochwalt was actively engaged in the work of the Manhattan District project of research on the atomic bomb and in the work of the National Defense Research Committee. He is in charge of the Mound Laboratories at Miamisburg, Ohio, and the Scioto Laboratories at Marion, Ohio.

He was elected a vice-president in May, 1947. Dr. Hochwalt was educated at the University of Dayton, from which he received degrees of B.Ch.E. and D.Sc.

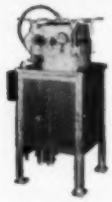
Walter J. Armstrong, assistant director of the Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill., has been in Costa Rica, C. A., under a research program, authorized by Congress and undertaken upon request of the Reconstruction Finance Corp., to aid in the output of Manila hemp fiber in Central America by increasing production efficiency and developing new uses for waste products from the process. **John D. Keane,** chemical engineer with the Foundation, is one of the group on this survey.

Charles H. Fisher is now assistant department engineer, engineering department, Calco chemical division, American Cyanamid Co., Bound Brook, N. J. He was formerly employed in the research and development department of Socony-Vacuum Oil Co., Paulsboro, N. J.

Edwin R. Gilliland, professor of chemical engineering at Massachusetts Institute of Technology, was recently elected to the board of directors of Dewey and Almy Chemical Co. Dr. Gilliland, who is also associate director of the nuclear science and engineering laboratories at M.I.T., has just received the Celanese Award from A.I.Ch.E.

HIGH VACUUM PUMPS REQUIRE CLEAN OIL

VACUUM PUMP USERS INSTALL HILCO OIL RECLAIMER SYSTEMS TO KEEP LUBRICATING AND SEALING OILS FREE OF SOLIDS, . . GUMS, . . WATER AND GASES



THE HILCO OIL RECLAIMER IS COMPLETELY AUTOMATIC

FOR BETTER VACUUM AND REDUCED VACUUM PUMP MAINTENANCE COSTS INVESTIGATE THE HILCO OIL RECLAIMER

★ *WRITE FOR FREE LITERATURE . . A RECOMMENDATION WILL BE MADE . . NO OBLIGATION ON YOUR PART.*

THE HILLIARD CORP.
144 W. 4th ST., ELMIRA, N. Y.

IN CANADA — UPTON-BRADEEN-JAMES LTD. 990 BAY ST., TORONTO—3484 PARK AVE., MONTREAL

Save Time, Labor, Dollars!

TEST • STUDY • CONTROL VISCOSITY

As Simply, Quickly and Easily as Taking Temperature Readings

Just a flick of a switch, then read the Brookfield dial, and you have your viscosity determination in centipoises. The whole operation, including cleaning up, *takes only a minute or two.*

Available in a variety of models suitable for extremely accurate work with both Newtonian and non-Newtonian materials, Brookfield Viscometers are portable and plug in any A. C. outlet — *can be used in Lab, Plant or both.*

Write today for fully illustrated catalog showing Brookfield Viscometers adaptable to any viscosity problem *from less than one to 32,000,000 centipoises.*

BROOKFIELD COUNTER-ROTATING MIXER — Two concentric, oppositely rotating shafts, propeller equipped and driven by two motors, produce an annular flow and up to 48,000 scimoter-like cuts/minute. Enable exceptionally fast, effective and efficient laboratory mixing. *Not* a "stirrer." Write for Brookfield MIXER brochure.

Brookfield ENGINEERING LABORATORIES, INC. 220 PORTER ST., STOUGHTON, MASS.

KUHL NAMED ESSO'S ASST. GEN. MGR. MFG.

Paul E. Kuhl, who has been serving as assistant general manager of East Coast manufacturing, has begun a one-year period as assistant general manager of Esso Standard Oil Co.'s over-all manufacturing operations. The position, a newly created one, was established as a part of the company's management development program. Present plans provide that the job will be filled on a rotational basis.

Mr. Kuhl has been with Esso Standard since 1926, when he joined the company as a student engineer. After serving with the old development division and the technical service division, he went to Aruba as assistant superintendent of the refinery there in charge of the technical department in 1932.

Subsequently he was assistant manager and then associate manager of the Standard Oil Development Co.'s process division. He became assistant manager of the southern East Coast units in 1944, manager in 1945. He moved to New York in March, 1948.

Ernest S. Robson, Jr., formerly petroleum chemicals salesman in Monsanto's St. Louis office, has been transferred to the Western division's office in San Francisco. Mr. Robson has been with Monsanto since 1941 when he was graduated from the University of Missouri with a B.S. degree in chemical engineering. Prior to entering the petroleum chemical sales department, Mr. Robson held various laboratory, production and sales positions.

Roy J. Diworky, executive vice-president of Pan-Am Southern Corp., New Orleans, La., has assumed the duties of president during the absence of B. K. Brown, who has been appointed deputy administrator of the petroleum administration for defense. The acting Pan-Am Southern president formerly served with Standard Oil Co. (Ind.) in research and manufacturing. Mr. Diworky's election as vice-president of Pan-Am Southern was referred to in the January, 1950, issue of "C.E.P.," page 40.

Gustav Egloff, director of research, Universal Oil Products Co., Chicago, Ill., was elected by the University of Edinburgh's Senatus Academicus to give the biennial "Romanes Lecture in Chemistry for 1951." Dr. Egloff, who is vice-president of the Third World Petroleum Congress, will attend the Third Congress, in the Hague, May 28-June 6, 1951, at which time he will lecture on "Polymerization of Olefinic Hydrocarbons."

PACIFIC
CORROSION RESISTANT* **VALVES**

150 LB. SERIES
GATE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 8"
Scr'd. Ends: ½" to 3"
Manufactured to M.S.S. St'ds. Also Available with A.S.A. Flanges.

150 LB. SERIES
GATE VALVE
Inside Screw, Screwed Bonnet, Solid Wedge
Scr'd. Ends: ½" to 2"
Manufactured to M.S.S. St'ds.

600 LB. SERIES
GATE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 2"
Scr'd. Ends: ½" to 2"
Manufactured to A.S.A. and A.P.I. St'ds.

150 LB. SERIES
GLOBE VALVE
O. S. & Y.-Bolted Bonnet
Flg'd. Ends: ½" to 4"
Scr'd. Ends: ½" to 1½"
Manufactured to M.S.S. St'ds.

150 LB. SERIES
SWING CHECK
Bolted Bonnet
Flg'd. Ends: ½" to 4"
Scr'd. Ends: ½" to 1½"
Manufactured to M.S.S. St'ds.

*These Valves are regularly furnished of Type 316 or Alloy 20 Stainless Steels. Other available Corrosion Resistant Alloys, including Monel and Hastelloy can be supplied.

PACIFIC VALVES, INC.
3201 WALNUT AVE., LONG BEACH 7, CALIFORNIA
TELEPHONES: L. B. - 40-5451; Los Angeles - NEvada 6-2325
TELETYPES: L. B. - B-8076; New York City - 1-1077
Houston, Texas - HO 489

CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements one-inch deep are available at $15 an insertion. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 25th of the month preceding the issue in which it is to appear.

SITUATIONS OPEN

Wanted: Chemical Engineers for process development and process design on petroleum refining and chemical processes. Prefer individuals with several years' experience in one or both of above fields. Southwest location. Write F. J. Heller, Research and Development Department, Phillips Petroleum Company, Bartlesville, Oklahoma.

Chemical Process Engineers

Qualified to prepare engineering studies and detailed process designs for petroleum and chemical fluid process plants. Salaried position; location in Boston. In reply please state education qualifications, work experience, and salary desired. Present employers will not be contacted before personal interview. Stone & Webster Engineering Corporation, 49 Federal St., Boston 7, Mass.

SITUATIONS WANTED

A.I.Ch.E. Members

Process Engineer—B.S.Ch.E.—6½ years in oil refining, synthetic fuels, ammonia, and petro-chemicals. Excellent experience in process design, economic evaluation, and pilot plants. Desire responsible position with aggressive oil or chemical company. Box 1-1.

Research Chemical Engineer—27, M.Ch.E., P. E. N. Y. State. Six years' diversified experience including one year pilot plant operation. Four years inorganic process development. Thorough knowledge thermochemical, physical chemical and process calculations. Experience with all techniques for conceiving and evaluating new chemical processes. Box 2-1.

Chemical Engineer—M.S., Columbia, 1950. Excellent scholastic record, Tau Beta Pi, Sigma Xi. Over one year varied experience in responsible position with small company. Veteran, single, 25. Desire position in development or technical service. Box 3-1.

M.S.Ch.E.—Three years' process development and construction engineer in organic chemicals. 1½ years' equipment design, sales; 6 years development engineering, cost analyses, in inorganic chemicals. Active A.I.Ch.E. Patent disclosures. 34, family. Want active responsible program. Box 4-1.

Chemical Engineer—B.Ch.E. 1940, M.S. 1946. Married, 31. Ten years' varied responsible experience including research and development in wood chemicals and; synthetic rubber and research in combustion and fluid mechanics. A.C.S. member, Associate Sigma Xi. Box 5-1.

Chemical Engineer—B.S., M.S., age 31. Licensed New York and New Jersey. Nine years' experience instrumentation, plastics process development and fabrication with leading firm. Desire position with consulting firm, small chemical, plastics, or fabricating company. Box 6-1.

Research Administrator—Engineer-Attorney. Eight years' varied technical, legal and administrative experience in the chemical and petroleum industries. Two years responsible administration with leading research organization. Seeking challenging position as business manager of research organization or administrative assistant to research director. Box 7-1.

Chemical Engineer—M.S. Univ. of Michigan. Seven years' responsible and diversified experience in production, research and development. Good initiative and drive. Not U. S. citizen. Desire engineering or administrative opportunity anywhere in the world. Box 8-1.

Chemical Engineer—B.E., age 28, veteran, family. Process and development engineering; six years' experience inorganic chemicals, design, unit operations, complete plants. Desire senior engineering or responsible management position with future. Box 9-1.

Chemical Engineer—M.S., M.I.T.; Tau Beta Pi. Age 26, family. Three years' successful, profitable experience in the study and design of new chemical processes. Desire research, development, or production position in Northeast. Box 10-1.

Chemical Engineer—Ph.D. Early thirties, with several years diversified experience in the chemical industry. Also two years academic research in agitation. Desire responsible position in creative engineering research either in private industry or in a progressive academic institution. Box 11-1.

PEOPLE

(*Continued from page* 45)

C. H. Pedersen is now associated with Electric Steel Foundry Co., Seattle, Wash. As sales engineer he is servicing the pulp and paper industry in northwestern Washington. He was previously design engineer with H. A. Simons, consulting engineers at Vancouver, British Columbia.

Carl W. Westphal, technical representative of the Dorr Co. in South America, has returned to South America after his first vacation in the United States in three years, and will now be located temporarily at Apartado 1763, Lima, Peru, instead of in his former headquarters in Buenos Aires, Argentina. During his stay in the United States he reviewed his company's latest technical developments, and on his way back conferred with his company's associated companies in Europe.

Warren H. Leverett, previously manager of the National Zinc Co., Inc., has been elected president of National Zinc Co., Inc., to fill the position vacated by the retirement of **Benno Elkan** who has held that position since the founding of the company. Mr. Leverett's office will be at 11 Broadway.

J. C. HOSTETTER HONORED

The recipient for the Albert Victor Bleininger Award of 1950 has been named as John C. Hostetter, Corning Glass Works scientist and recent president of the Mississippi Glass Co. This announcement was made at the December meeting of the Pittsburgh Section of the American Ceramic Society. The award is given annually to an outstanding man in ceramics. Presentation of the award, symbolized by a medal and scroll, will be made at a testimonial banquet at the Hotel Schenley in Pittsburgh March 16, 1951.

In a long career, Dr. Hostetter was associated with the National Bureau of Standards, the Geophysical Laboratory of The Carnegie Institution of Washington, and was director of research and development at the Corning Glass Works, Corning, N. Y. Later Dr. Hostetter served as vice-president and director of research for the Hartford-Empire Co., Hartford, Conn., and was president of the Mississippi Glass Co., St. Louis, Mo. He recently retired.

C. F. Prutton, vice-president, Mathieson Chemical Corp., has been appointed a member of the standing committee on manpower of the Manufacturing Chemists' Association to deal with chemical manpower probelms arising out of the war emergency.

Murray C. Slone is now on special duty with the U. S. Army as a chemical engineer at the National Bureau of Standards, Washington, D. C. Prior to his being called he was associated with the U. S. Bureau of Mines, Gorgas, Ala.

G. J. F. Breedveld, formerly assistant refinery superintendent Curacao Petrol Indus. Mij. Emmastad, Curacao, N.W.I., is now refinery superintendent, Bataapche Mij. (Shell), Pladjoe (Palembang) Indonesia.

John E. McKeen, president of Charles Pfizer & Co., of New York, was recently elected to the directorate of the Manufacturing Chemists Association, Inc., New York.

Willis M. Cooper, assistant to the managing director of Monsanto Chemicals Limited, London, England, has been appointed assistant director of Monsanto's general engineering department in St. Louis. The appointment was effective Dec. 1. Mr. Cooper was graduated from Iowa State College with a B.S. degree in chemical engineering in 1935. He joined Monsanto in the same year as a laboratory analyst. In 1941, he was assigned as a chemical engineer to the Texas City (Tex.) plant. Mr. Cooper joined the general engineering department in 1943, and three years later was appointed manager of engineering for Monsanto's British operations. He was named assistant to the managing director of the British company in May of this year.

Austen W. Boyd of the General Electric Co.'s chemical department, has been appointed in charge of the chemical process development Waterford (N. Y.) group. A 1943 graduate of Cornell University with a Bachelor's degree in chemical engineering, Mr. Boyd first went with the G. E. in 1946 as a chemical engineer. Previously he was associated with the Tidewater Association as a research assistant. Earlier this year, Mr. Boyd was a winner of the Coffin Award, the G. E.'s highest honor to employees.

Mark W. Swetland and Martin Grad, both junior engineers, have been advanced to project engineer and process engineer, respectively, of the Vulcan Copper & Supply Co., Cincinnati, Ohio.

William J. Hallett, formerly engineer with the Fairchild Engine & Airplane Corp. (N.E.P.A. division), Oak Ridge, Tenn., has accepted a position as research engineer with the North American Aviation, Inc., in the atomic energy research department, Downey, Calif.

Ralph W. Yula, formerly project engineer, Arthur G. McKee Co., Union, N. J., is now a partner in the firm of R. S. Aries & Associates, consulting engineers, New York, N. Y.

W. Myers, a recent graduate from the Case Institute of Technology in chemical engineering, has been added to the staff of the development division of the Diamond Alkali Co.'s Painesville (Ohio) plant.

John W. Palm, research and development engineer with the Cities Service Oil Co., Tallant, Okla., has left that connection. He has started graduate work in chemical engineering at the University of Michigan. He had been chairman of the Oklahoma Section of A.I.Ch.E.

Graduate Engineers

GOOD OPPORTUNITIES for

CHEMICAL ENGINEERS: Five to ten years' experience in Chemical Operations or Development. Work in Application of unit operations, evaluations and economic studies leading to cost reduction. Must be graduate, free to travel.

PROCESS ENGINEERS: Must have at least eight years' industrial plant design and experience with at least three years in responsible charge of design work. Plant experience desirable. Must have experience in chemical plant design calculations, equipment design and plant arrangement, with knowledge of structural, power, instrumentation design, etc. Must be graduate.

ENGINEERS FOR UNIT OPERATIONS: Five years' experience in the fields of Agitation, Drying or Grinding, Blending and Screening. Specialized knowledge of Heat Transfer, Fluid Flow and Mass transfer are desirable. Must be graduate. Consultation work.

ENGINEERING MATERIALS ENGINEER: Five to ten years' experience in Engineering work dealing with corrosion problems, metallurgical investigations, selection and specification for rubber, ceramics and plastics for various uses, fabrication, heat treatment, forming, lining, etc. Must have broad knowledge of Materials of Construction and for Construction, their production, fabrication and installation. Must be graduate. For consultation work.

METALLURGICAL RESEARCH ENGINEERS: M.S. or Ph.D. in Metallurgical Engineering. Must have at least a few years research experience and be interested in research and development in materials and construction for the chemical industry.

INSTRUMENTATION ENGINEERS: Five or more years of progressively difficult experience in Instrument Research Development or design. Must have broad and thorough knowledge of instrument theory and application. Should have some knowledge of Chemical Equipment and its operation. Must be graduate.

MATERIALS HANDLING ENGINEERS: Must have eight to twelve years' broad and thorough experience with operation, uses of all types of materials handling equipment. Must be familiar with chemical equipment and its operation. Also interested in such engineers with specific experience in wide range of bulk materials handling. Must be graduate.

Give experience, education, age, references, personal history, salary received and salary expected. Please be complete and specific.

All inquiries will be considered promptly and kept confidential

E. I. du Pont de Nemours & Co. (Inc.)

Engineering Department Personnel

WILMINGTON 98, DELAWARE

ACRAGAGE
Shockstop!
PAT. APPLIED FOR
Protects against Pulsation and Shock!

Eliminates Snubbers— It Can't Plug—
The Most Significant Pressure Gage Development in 50 Years.
For the first time, a successful means of eliminating the effect of pulsation and shock on pressure gage mechanisms has been developed which DOES NOT introduce an orifice or restriction in the pressure connection. It Can't Plug
FOR COMPLETE INFORMATION, WRITE FOR CATALOG C-50-C
ACRAGAGE CO.
Formerly Clapp Instrument Co.
MILFORD, CONN.

PLATE FABRICATION
CHROME IRON ALLOYS
CARBON STEEL
CHROME NICKEL
SILICON BRONZES
MONEL • ALUMINUM
NICKEL CLAD STEEL • ETC.
Towers, Pressure Vessels and General Plate Fabrication manufactured with trained personnel and up-to-date equipment. Our Engineers will assist in designing to meet your requirements.
Good Design — Right Material — Expert Workmanship at a Fair Price.
HEAT EXCHANGERS A SPECIALTY
Fabricators and Designers for More Than 30 Years
Use our valuable new Bulletin as a handy reference guide . . . contains partial analysis of 1950 A.S.M.E. Code for Unfired Pressure Vessels.
DOWNINGTOWN IRON WORKS
DOWNINGTOWN, PA.
WELDED and RIVETED PRODUCTS

ON NEW YORK SALES STAFF OF WHITING

Two additions to the New York sales staff of Whiting Corp.: William G. Dedert and Warren E. Hesler. Both men will devote full time to the sale and engineering of Swenson products, including evaporators, filters, crystallizers, pulp-mill equipment and spray-drying systems. The Swenson Evaporator Co. is a division of Whiting Corp., Harvey, Ill.

W. E. Hesler is a graduate engineer of Northwestern (1944). After serving as an officer in the Navy (Pacific area) he entered the employ of the U. S. Rubber Co., foam rubber division; since 1947 he has been with Swenson Evaporator in an engineering capacity.

W. G. Dedert is a graduate chemical engineer from Rose Polytechnic Institute (1945). For the past five years he has been employed at the main office and plant of Swenson Evaporator Co., specializing in the design and sale of pulp-mill recovery equipment.

HENRY HOWARD AWARDED 1951 PERKIN MEDAL

Henry Howard, Past President of the American Institute of Chemical Engineers, long prominent in American chemical industry and for 22 years chairman of the executive committee of the Manufacturing Chemists' Association, has been selected to receive the 1951 Perkin Medal. An announcement to this effect was made recently by Gustavus J. Esselen, honorary chairman of the American section of the Society of Chemical Industry, which sponsors the award.

Mr. Howard, a native of Jamaica Plain, Boston, Mass., was for 32 years connected in various capacities with the Merrimac Chemical Co., now a part of the Monsanto Chemical Co., and for ten years subsequent to that he was successively director of new products department, director of research and development, and consultant to the Grasselli Chemical Co., now a part of the Du Pont Co.

Mr. Howard's contributions to American chemical industry included developments connected with sulfuric acid production, the use of Spanish pyrites as a raw material, the development of British Guiana bauxite deposits as chemical raw material and the invention and improvement of instruments and equipment used in chemical manufacture. Eighty-nine patents have been issued to him.

Presentation to Mr. Howard will be made in New York April 27, 1951. Details of that meeting will be announced later.

M. S. McCauley, production coordinator of the Monsanto Chemical Co.'s John F. Queeny plant in St. Louis, was recently appointed sales projects manager of the company's organic chemicals division. In his newly created post Mr. McCauley will be responsible for the plotting of both long- and short-range sales requirements and the budgeting of raw materials and production.

A native of St. Louis, Mr. McCauley has been with Monsanto since 1929, when he was graduated from Washington University with a B.S. degree in chemical engineering. Prior to becoming production coordinator in 1943, he had served in various research and production capacities. He is the author of several papers on analytical methods.

Necrology

W. C. FRISHE

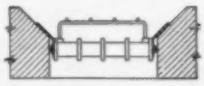
William Christopher Frishe, since September, 1950, professor of chemical engineering at the University of Detroit, Detroit, Mich., died recently. He had been previously associated with the chemical engineering department of the Clarkson College of Technology, Potsdam, N. Y. Dr. Frishe was 38 years old. He received an M.S. in chemical engineering and chemistry from the University of Cincinnati in 1938 and a Ph.D. in physical chemistry in 1943 from Indiana University. Early in his short career he was associated with the Alabama Polytechnic Institute, Auburn, Ala., and with the Girdler Corp. in Louisville, Ky. Before accepting the appointment at Clarkson College he had served as professor of chemical engineering and metallurgy at Grove City College, Grove City, Pa.

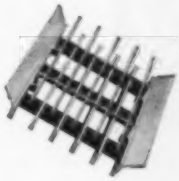
INDEX OF ADVERTISERS

	Page
Acragoge Co.	48
American Instrument Co., Inc.	41
Annin Company	29
Ansul Chemical Co.	19
Badger & Sons Co., E. B.	5
Bauer Bros. Co.	49
Beckman Instruments, Inc.	21
Bin-Dicator Co.	43
Black, Sivalls & Bryson, Inc.	24, 25
Brookfield Engineering Labs., Inc.	45
Carbide & Carbon Chemicals Div.,	*Inside Front Cover*
Crane Company	8
Croll-Reynolds Co., Inc.	49
Dow Chemical Co.	34
Downingtown Iron Works	48
Du Pont de Nemours & Co., (Inc.), E. I.	47
Fischer & Porter Company	*Back Cover*
Floridin Company	38
Fluor Corp., Ltd.	23
General American Transportation Corp.	2
Glycerine Producers' Association	7
Gump Company, B. F.	3
Hardinge Co., Inc.	40
Haynes Stellite Co.	17
Hilliard Corp., The	45
Hills-McCanna Co.	36
Lapp Insulator Co.	33
Lawrence Machine & Pump Corp.	39
Link-Belt Company	6
Louisville Drying Machinery Unit, General American Transportation Corp.	2
Mercoid Corp.	41
Milton Roy Company,	*Inside Back Cover*
Minneapolis - Honeywell Regulator Co.	27
National Carbon Div.	31
Nicholson & Co., W. H.	43
Pacific Valves, Inc.	45
Patterson Foundry & Machine Co.	44
Pfaudler Company, The	10
Pritchard & Co., J. F.	50
Sharples Corp., The	4
Sparkler Mfg. Co.	37
Sperry & Company, D. R.	18
Standard Steel Corp.	42
Standard Stoker Co., Inc.	35
Stephens-Adamson Mfg. Co.	9
Union Carbide & Carbon Corp.,	*Inside Front Cover*, 17, 31

THE IRONY OF THE MAGNETIC GRATE

Bauer





A permanently magnetized grate is such an obvious thing that we should have thought of it years ago. But we didn't; and that's the irony of it. A customer gave us the idea!

When flowable materials are poured or dumped or shoveled through the Magnetic Grate, iron and steel inclusions simply can't get by. What's more, the grate catches large debris such as strings, rags, paper, and sticks.

Installation consists merely of laying the Magnetic Grate on a frame in a hopper or floor opening as shown in the drawing. The size may be anywhere from 2"x 4" to as many feet wide and long as desired.

Ask for Bulletin M-3-A which describes all Bauer Permanent Magnetic Separators. Write, phone, or wire us while you're thinking of it.

THE BAUER BROTHERS CO.

1794 SHERIDAN AVE. • SPRINGFIELD, OHIO

Bauer

LINE OF FOOD PROCESSING EQUIPMENT

•

DOUBLE and SINGLE DISC ATTRITION MILLS

•

HAMMER MILLS

•

CRUSHERS, CRUSHER-FEEDERS, BREAKERS

•

Mechanical, Pneumatic, Gravity, and Magnetic Separators

•

Hullers, Cleaners, Shakers, Aspirators, Exhaust Fans

•

Nut Blanchers, Roasters, Granulators, Butter Mills and Texturizers

•

LABORATORY MILLS

IS VACUUM THAT'S 99.99% PERFECT good enough for *your* process?

THIS degree of vacuum is easily obtained with the Croll-Reynolds four or five-stage steam jet EVACTOR, with no moving parts. Each stage from a technical standpoint is as simple as the valve that turns it on. Numerous four-stage units are maintaining industrial vacuum down to 0.2 mm. and less, and many thousands of one, two and three stage units are maintaining vacuum for intermediate industrial requirements on practically all types of processing equipment.

By permitting water, aqueous solutions or any volatile liquid to evaporate under high vacuum and without heat from an outside source, enough BTU's can be removed to chill the liquid down to 32° F., or even lower in the case of solutions. This is the principle of the Croll-Reynolds "Chill-Vactor." Hundreds of these have been installed throughout the United States and in several foreign countries.

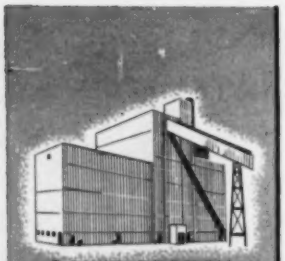
An engineering staff of many years experience has specialized on this type of equipment and is at your service. Why not write today, outlining your vacuum problem?

CROLL REYNOLDS

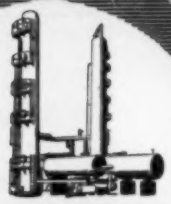
CROLL-REYNOLDS CO., INC.

17 JOHN STREET, NEW YORK 7, N. Y.

Chill-Vactors Steam Jet Evactors Condensing Equipment

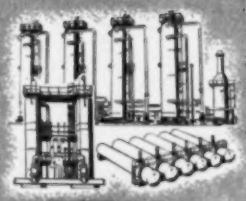


POWER DIVISION



CHEMICAL DIVISION

PETROLEUM DIVISION



NATURAL GAS DIVISION

DESIGN ENGINEERING and CONSTRUCTION for INDUSTRY

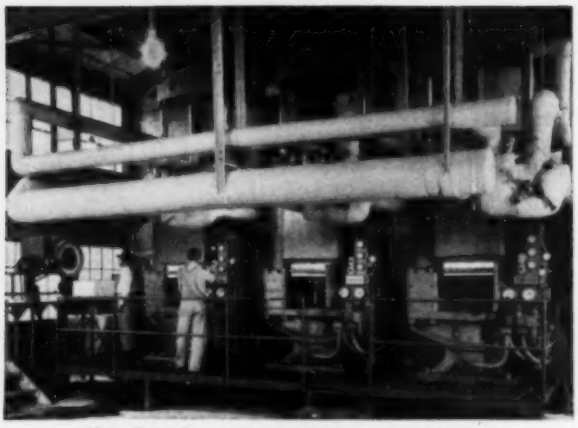


Photo shows three semi-automatic dry ice presses turning out 200 lb. blocks of dry ice in a well known midwestern plant designed and engineered by Pritchard.

Pritchard-Built Plants— *OUTSTANDING* in the Industry

Pritchard-built "dry-ice" and liquid CO_2 plants are *outstanding* for their low cost, operating efficiency and production to the *exacting* quality standards set by the purchaser.

But "dry-ice" plants are only one of many types which Pritchard builds for the chemical industries. Our wealth of technical "know-how" and experience acquired through the years are your guarantee of an *outstanding* plant whenever Pritchard's services are utilized.

Whether you need complete "turnkey" service to include processing, design, engineering, procurement and construction—or whether you desire merely to supplement the work of your own engineering staff, Pritchard's services are *flexible* to provide assistance and close cooperation in whatever degree your project may require.

Call in a Pritchard engineer when you plan your next project. Let him show you how to make it one of the *outstanding* in the industry!

Write for Catalog 0.94.001

NATIONAL CONSTRUCTORS ASSOCIATION MEMBER

J.F. Pritchard & Co.

DESIGN • ENGINEERING • CONSTRUCTION

Dept. No. 97 908 Grand Ave., Kansas City 6, Mo.

District Offices:
Chicago • Houston • New York • Pittsburg • Tulsa • St. Louis

...thank you!

AMERICAN CYANAMID CO.

AND YOUR PLANT ENGINEERING GROUP

Thank you for your many purchases of Milton Roy Controlled Volume Chemical Pumps over the past ten years, and for your courtesy in permitting us to run this announcement for all the world to see.

American Cyanamid was one of our first big-name customers . . . now has well over one hundred units in plants from Florida to California.

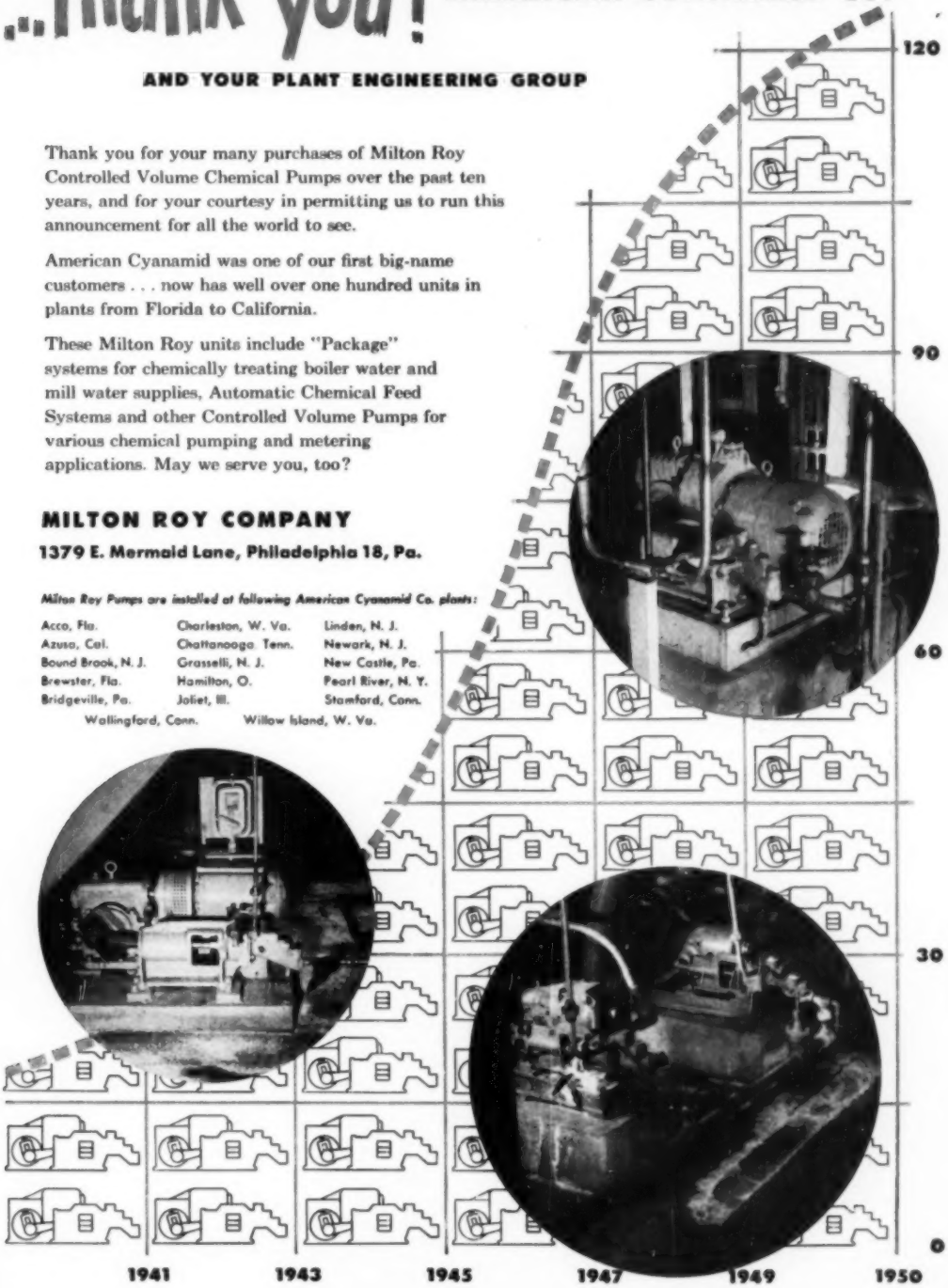
These Milton Roy units include "Package" systems for chemically treating boiler water and mill water supplies, Automatic Chemical Feed Systems and other Controlled Volume Pumps for various chemical pumping and metering applications. May we serve you, too?

MILTON ROY COMPANY

1379 E. Mermaid Lane, Philadelphia 18, Pa.

Milton Roy Pumps are installed at following American Cyanamid Co. plants:

Acco, Fla.	Charleston, W. Va.	Linden, N. J.
Azusa, Cal.	Chattanooga, Tenn.	Newark, N. J.
Bound Brook, N. J.	Grasselli, N. J.	New Castle, Pa.
Brewster, Fla.	Hamilton, O.	Pearl River, N. Y.
Bridgeville, Pa.	Joliet, Ill.	Stamford, Conn.
Wallingford, Conn.	Willow Island, W. Va.	



NEW!
LOW-CAPACITY MAGNABOND *FLOW METER*

The MAGNABOND meter which has won wide acceptance in the chemical and process industries has been extended in scope to cover *new low flow* rates. These low flow ranges can be indictated, recorded, and/or controlled accurately with unequalled economy and are especially suitable for pilot plant and semi-works operations.

RANGE OF CAPACITIES

Smallest size MAGNABOND meter		Largest size MAGNABOND meter	
MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
*0.33 GPM	0.033 GPM	*5500 GPM	550 GPM
**1.40 SCFM	0.140 SCFM	**15,000 SCFM	1500 SCFM

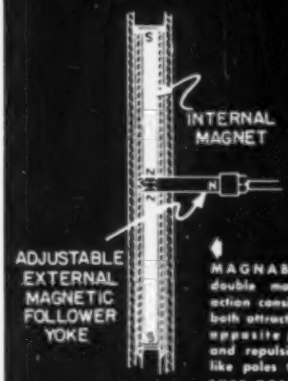
*In terms of water equivalent
**In terms of air equivalent (@ 14.7 psia & 70° F)

SAFE, POSITIVE, FRICTIONLESS COUPLING

A patented magnetic transmission of float position from a metering tube to an external follower makes possible a new degree of safety and convenience in instrumentation. Pressure-tight bearings are eliminated and the unique MAGNABOND eliminates the possibility of separation of float and follower no matter how fast or how often flow rates change.

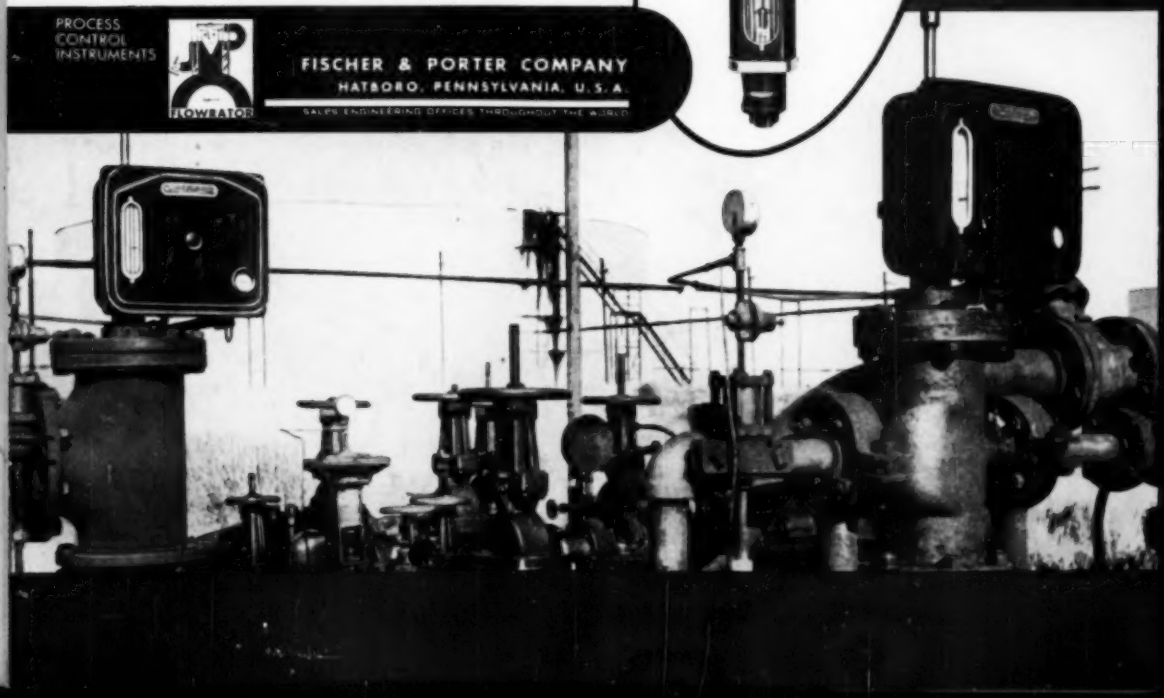
The MAGNABOND Flow Meter measures, controls, and totalizes corrosive, inflammable, or opaque fluids—at high pressure or high temperature—with dependable accuracy.

WRITE FOR CATALOG 50



MAGNABOND double magnetic action consists of both attraction of opposite poles and repulsion of like poles to assure positive transmission.

Fig. 735 FLOW-RATOR meter with MAGNABOND-operated indicator and pneumatic remote transmitter.



installation of MAGNABOND FLOW-RATOR Meters with pneumatic transmission on slop oil steam

PROCESS CONTROL INSTRUMENTS

FLOW-RATOR

FISCHER & PORTER COMPANY
HATBORO, PENNSYLVANIA, U.S.A.
SALES ENGINEERING OFFICES THROUGHOUT THE WORLD